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Operable Unit 3-14 Tank Farm Soil and Groundwater Feasibility Study

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Operable Unit 3-14 Tank Farm Soil and Groundwater Feasibility Study

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ABSTRACT

The Operable Unit (OU) 3-14 Feasibility Study is for the tank farm soil and groundwater located at the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho National Laboratory Site. The study is being conducted pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). This Feasibility Study identifies and analyses remedial alternatives to mitigate risks to human health and the environment from soil contaminated by releases from the liquid waste system at the INTEC tank farm and from groundwater contaminated by all INTEC CERCLA sources.

Concentrations of strontium-90 (Sr-90), technetium-99 (Tc-99), iodine-129, and nitrate-N currently exceed State of Idaho groundwater quality standards (maximum contaminant levels [MCLs]) in the Snake River Plain Aquifer (SRPA). The baseline risk assessment concluded that Sr-90 concentrations in the SRPA would exceed MCLs beyond the year 2095 and that cesium-137 concentrations in the soil will exceed risk-based levels after 2095. It also concluded that the other aquifer contaminants will meet MCLs by 2095.

Remedial action objectives (RAOs) and preliminary remediation goals are developed. The RAOs are designed primarily to protect workers from direct radiation exposure and ensure that the aquifer meets MCLs by 2095. Technologies that may potentially meet the RAOs are identified and screened. Representative technology process options that were retained after screening are combined into alternatives, ranging from limited action to alternatives incorporating containment, removal, and treatment of soil and groundwater. Although administratively, OU 3-14 includes the tank farm soil and SRPA affected by all INTEC CERCLA sources but not the intervening perched water, which is in OU 3-13, Group 4, some alternatives were developed that include actions to minimize migration of Sr-90 from perched water to the aquifer. The alternatives are evaluated with respect to CERCLA evaluation criteria in detail. Performance with respect to the evaluation criteria is compared among alternatives.

EXECUTIVE SUMMARY

Operable Unit (OU) 3-14 consists of the tank farm soil and groundwater located at the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho National Laboratory Site. The Remedial Investigation/Baseline Risk Assessment (RI/BRA) and Feasibility Study (FS) for tank farm soil and groundwater are being conducted pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). OU 3-14 was created to resolve data gaps that were identified in the OU 3-13 Comprehensive INTEC Record of Decision (ROD) and prevented attainment of remedial decisions for the tank farm soil and the Snake River Plain Aquifer (SRPA). A field investigation was performed for OU 3-14 in 2004 to resolve data gaps and complete the RI/BRA and the FS. This OU 3-14 FS identifies and analyses remedial alternatives to mitigate risks to human health and the environment from (a) soil contaminated by releases from the liquid waste system at the INTEC tank farm and (b) groundwater contaminated by all INTEC CERCLA sources.

The BRA concluded that cesium-137 (Cs-137) concentrations in the soil will continue to exceed risk-based levels after 2095 for soil inside the tank farm boundary but will meet risk-based levels before 2095 for the two sites outside the boundary. The groundwater beneath INTEC currently exceeds State of Idaho groundwater quality standards at one or more monitoring wells for strontium-90 (Sr-90) and iodine-129 from the former injection well and for technetium-99 and nitrate measured as nitrogen from historical tank farm releases. Modeling results predicted that Sr-90 concentrations in the SRPA would continue to exceed the State of Idaho groundwater quality standard beyond the year 2095, but all other contaminants would meet the standards before 2095. Remedial action objectives and preliminary remediation goals are defined in the FS based on the BRA predictions.

Release sites are combined into waste groups and subgroups with common media, contaminant sources and types, exposure pathways, and receptors to facilitate selection of remedial technologies. All of the soil release sites and contaminated backfill at the tank farm are included in the CPP-96 grouping, which was defined in the OU 3-13 ROD as “a consolidation of all of the previously identified Tank Farm Soil release sites and the intervening interstitial soil within the Site CPP-96 boundary.” The OU 3-13 ROD also deferred a final remedy decision for the SRPA affected by INTEC releases to OU 3-14. Groupings and subgroupings defined for the OU 3-14 FS, therefore, include

1. OU 3-14 Soil

    a. Soil Inside Tank Farm Boundary: Soil inside the tank farm boundary and potentially accessible only by workers: Sites CPP-16, CPP-20, CPP-24, CPP-25, CPP-26, CPP-27/33, CPP-28, CPP-30, CPP-31, CPP-32E/W, CPP-58W, CPP-79, and CPP-79 (deep) and contaminated backfill. These sites, referred to as Soil Inside Tank Farm Boundary, pose an unacceptable risk to current and future workers from direct exposure to Cs-137 contaminated soil. Although these sites do not pose an unacceptable risk to groundwater from residual contamination in the soil, they contribute slightly to overall groundwater risk. Because Site CPP-31 contains the highest residual mass of radionuclides at depth and is responsible for greater than 87% of radioactivity released from the tank farm, soil to bedrock (40-ft depth) at Site CPP-31 will be considered in the FS.

    b. Sites outside the tank farm boundary potentially accessible by workers: CPP-15 and CPP-58. These sites pose an unacceptable risk to current workers but not future workers due to radioactive decay.

2. The area of the SRPA contaminated by INTEC releases.

The area of the SRPA contaminated by INTEC releases includes areas both inside and outside the INTEC security fence. It contrasts with the area of the SRPA addressed in the OU 3-13, Group 4, perched water remedy, which was limited to the area outside the fence. The two operable units, although separate administratively, are integrated to ensure that the SRPA is protected both inside and outside the INTEC security fence.

Remedial action objectives (RAOs) that affect the SRPA are defined as follows:

I. Prevent groundwater ingestion prior to 2095: Prior to 2095, prevent current workers and the general public from ingesting SRPA groundwater contaminated by INTEC releases that exceeds applicable State of Idaho groundwater quality standards (currently identified as 8 pCi/L for Sr-90, 900 pCi/L for Tc-99, 1 pCi/L for I-129, and 10 mg/L for nitrate measured as nitrogen), a cumulative excess cancer risk from all carcinogens of 1 in 10,000, or an HI of 1.

II. Meet groundwater quality standards: In 2095 and beyond, ensure that concentrations of all contaminants in SRPA groundwater contaminated by INTEC releases do not exceed State of Idaho groundwater quality standards, a cumulative excess cancer risk from all carcinogens of 1 in 10,000, or an HI of 1.

RAOs I and II apply to the SRPA inside and outside the INTEC fence. Total excess cancer risk and HI will be determined by summing contaminants that are predicted to be in the SRPA at the same place and time. The results of the BRA model predicted that Sr-90 would exceed the maximum contaminant level (MCL) of 8 pCi/L in 2095 and beyond. No noncarcinogens have been identified that would exceed an MCL, and the total HI is currently below 1 and predicted to remain below 1.

RAO II can potentially be met through combinations of actions (a) on the alluvium and/or the SRPA under OU 3-14 and (b) on the vadose zone below the alluvium (perched water, interbeds, and/or basalt) and/or recharge (controls on infiltration and anthropogenic water) under OU 3-13 Group 4.

RAOs for the OU 3-14 soil are defined as follows:

III. Prevent exposure inside tank farm: Prevent external exposure to current and future workers inside the tank farm boundary to Cs-137 contaminated alluvium in the top 4 ft, including biotic transport, that would exceed an excess cancer risk of 1 in 10,000.

IV. Prevent exposure outside tank farm: Prevent external exposure to current workers at Sites CPP-15 and CPP-58 to Cs-137 contaminated alluvium in the top 4 ft that would exceed an excess cancer risk of 1 in 10,000.

V. Prevent ecological exposure: Prevent internal exposure to Cs-137 and Sr-90 inside the tank farm boundary that would exceed an ecological hazard quotient of 10 for an individual contaminant and a total HI of 10.

The RAOs for soil are focused on external exposure because exposure from gamma-emitting radionuclides represents the predominant risk. The risk and hazard quotient for other exposure routes, such as soil ingestion, are well below the risk threshold of 1×10^{-4} or the hazard quotient of 1 and are extremely small (0.0002% or less of the total) relative to impacts from external exposure. RAO III also addresses the potential for biotic transport of contamination as a possible pathway. To ensure the protection of workers, it is necessary to inhibit transport of contaminants of concern to the surface by plants and animals. Intrusion by deep-rooted plants and burrowing mammals and insects (ants) into contaminated soil can create a pathway for movement of contamination to the surface.

Technologies that may potentially meet the remedial action objectives for each subgrouping are identified and screened. Representative technology process options (RPOs) that were retained after screening were combined into a range of alternatives to meet RAOs for each grouping.

Administratively, OU 3-14 includes the tank farm soil and SRPA affected by all INTEC CERCLA sources but not the intervening perched water, which is in OU 3-13, Group 4. Because the effectiveness of the perched water remedy is a critical component of any remediation strategy for the SRPA in OU 3-14, Section 1.3.6 describes the effectiveness of the Group 4 remedy to date.

The INTEC model was used to simulate remedial actions that could be implemented under OU 3-13 or OU 3-14. These included (1) reduction of anthropogenic water recharge by 50% starting in 2008 through the life of INTEC operations (at which point water use should cease), (2) prevention of infiltration from the Big Lost River beginning in 2010, (3) reduction of infiltration through

10 acres in the area adjacent to the tank farm and through contaminated tank farm soil in 2012, and (4) immobilization of Sr-90 believed to exist in the alluvium at Site CPP-31 in 2008. The model simulations included these four remedial actions separately and various combinations of the four. The results of these model simulations were used to formulate the remedial action alternatives.

Alternatives were formulated that include actions to control and reduce recharge to the perched water. The alternatives range from a limited action alternative, incorporating institutional controls and monitoring; to alternatives incorporating containment, removal, and treatment of contaminated soil and groundwater. The range of alternatives was formulated to cover the range of possible BRA outcomes and to address constraints on implementability presented by existing and future INTEC infrastructure and operations.

Alternatives include

– Alternative 1—Institutional Controls, Operations and Maintenance, and Monitoring. This will be referred to as limited action and meets the intent of the No Action alternative.

– Alternative 2a—Institutional Controls, Monitoring, Excavation and Containment by 2012. Alternative 2b—Institutional Controls, Monitoring, Excavation and Containment by 2035. Capping would be implemented in phases with a low-permeability asphalt cover to control infiltration by 2012 and final capping by 2035 when infrastructure constraints are removed.

– Alternative 3a—Institutional Controls, Monitoring, Excavation, Source Removal and Containment by 2012.

– Alternative 3b—Institutional Controls, Monitoring, Excavation, Source Removal and Containment by 2035. The remedy would be implemented in phases with a low-permeability asphalt cover to control infiltration by 2012 and source removal and final capping by 2035 when infrastructure constraints are removed.

– Alternative 4a—Institutional Controls, Monitoring, Excavation, Source Treatment and Containment by 2012.

– Alternative 4b—Institutional Controls, Monitoring, Excavation, Source Treatment and Containment by 2035. The remedy would be implemented in phases with a low-permeability asphalt cover to control infiltration by 2012 and source treatment and final capping by 2035 when infrastructure constraints are removed.

– Alternative 5—Contingent Snake River Plain Aquifer Pump and Treat for Cleanup. This will be referred to as contingent pump and treat. It would only be implemented in approximately 2077 if Alternatives 2a, 2b, 3a, 3b, 4a, or 4b had already been implemented and determined through groundwater monitoring not to be sufficiently protective of the aquifer.

The performance of alternatives in meeting SRPA RAOs was evaluated. The primary consideration in assessing the threshold criterion of overall protection of human health and the environment is whether an alternative meets the RAOs. The INTEC groundwater model developed for the RI/BRA was used to simulate individual remedial actions and predict the effect the actions would have on reducing future groundwater concentrations. Conceptual designs and supporting capital and operations and maintenance cost estimates were developed in sufficient detail to meet the target cost range of -30 to +50%.

The alternatives are analyzed in detail, both individually and in comparison with each other, with respect to CERCLA evaluation criteria, including

– Threshold criteria

  (1) Overall protection of human health and the environment

  (2) Compliance with applicable or relevant and appropriate requirements

– Balancing criteria

  (1) Long-term effectiveness and permanence

  (2) Reduction of toxicity, mobility, or volume through treatment

  (3) Short-term effectiveness

  (4) Implementability

  (5) Cost.

Two other criteria, state acceptance and community acceptance, will be evaluated following comment on the Proposed Plan.

This approach provides a basis for the risk managers (U.S. Department of Energy Idaho Operations Office, the Environmental Protection Agency Region 10, and the State of Idaho Department of Environmental Quality) to identify the alternatives that will mitigate unacceptable risks and meet threshold criteria and best meet balancing and modifying criteria.

Results of the detailed and comparative analysis with respect to the CERCLA evaluation criteria are summarized below:

Overall protection of human health and the environment–All alternatives, including Alternative 5 (contingent pump and treat in combination with another alternative) would meet groundwater RAO I (prevent ingestion) by implementing institutional controls, including access restrictions through at least 2095. Alternatives 2a, 2b, 3a, 3b, 4a, and 4b would meet groundwater RAO II (meet groundwater quality standards by 2095). Implementing potential OU 3-13 Group 4 remedies would further improve attainment of the RAO. Alternative 5 would meet RAO II by removing Sr-90 from SRPA groundwater.

Alternative 1 (limited action) meets soil RAO III (prevent exposure inside tank farm) for current workers only and meets soil RAO IV. Alternatives 2a, 2b, 3a, 3b, 4a, and 4b meet RAOs III and IV equally well. Alternative 1 does not meet soil RAO V (prevent ecological exposures). Alternatives 2a, 2b, 3a, 3b, 4a, and 4b would meet RAO V equally well by capping or removing and capping contaminated soil. Alternative 5 is a groundwater remedy that would only be implemented after a remedy for soil exposure risks had already been implemented.

Compliance with applicable or relevant and appropriate requirements (ARARs) and to-be-considered (TBC) criteria–Results indicate that Alternatives 2a, 2b, 3a, 3b, 4a, 4b, and 5 would meet all action and chemical-specific ARARs and TBCs identified, including Idaho Ground Water Quality Rules, by 2095. Alternative 1 would not meet Idaho Ground Water Quality Rules in 2095, based on groundwater modeling predictions.

Long-term Effectiveness and Permanence–Alternative 1 (limited action) would provide no long-term effectiveness or permanence. Containment Alternatives 2a and 2b would provide long-term effectiveness and permanence for contaminated soil by removing and disposing of some soil in the Idaho CERCLA Disposal Facility (ICDF) followed by capping. Alternatives 3a and 3b would provide the most long-term effectiveness and permanence by also removing and disposing of CPP-31 soil prior to capping. Grouting (Alternatives 4a and 4b) would provide comparatively less long-term effectiveness and permanence than removal (Alternatives 3a and 3b), because in situ grouting of CPP-31 soil would not be completely effective. Alternative 5 (contingent pump and treat) would provide long-term effectiveness and permanence for the SRPA by removing Sr-90 from extracted groundwater by ion exchange and disposing of the ion exchange resins in an ICDF-equivalent facility.

Reduction of Toxicity, Mobility and Volume Through Treatment Only–Grouting alternatives (4a and 4b) and Alternative 5 (contingent pump and treat) would implement treatment to reduce toxicity, mobility, and volume of contaminants. Alternatives 4a and 4b would not be completely effective in contacting Sr-90 contamination at CPP-31 with grout because of infrastructure. SRPA pumping and treatment implemented as part of Alternative 5 would reduce the mass and mobility of Sr-90 and the volume of contaminated water until 2095. However, very small amounts, i.e., less than 0.1 Ci, would be recovered. Secondary wastes, including spent ion exchange resins, regenerant, and treated groundwater, would be produced.

Short-Term Effectiveness–No added risks to the public or the environment would result from implementing any of the alternatives. Alternative 1 would have the lowest risks to workers and therefore the best short-term effectiveness. Perimeter soil removal and cap construction implemented as part of Alternatives 2a, 2b, 3a, 3b, 4a, and 4b would have incrementally higher risks to workers.

Grouting alternatives (4a and 4b) would have increased chances of worker exposures and injuries due to production of radioactive drill cuttings and grout returns and use of high-pressure fluids. Mitigating risks and hazards would require significant administrative and engineering controls. Removal alternatives (3a and 3b) would have the highest worker direct radiation exposures and would require more substantive administrative and engineering controls, including shielding and a work enclosure.

Risks resulting from groundwater pumping and treatment implemented as part of Alternative 5 could be readily mitigated by INL Site work controls and engineering controls.

Implementability–Alternative 1 would be the most readily implementable alternative. Capping the central tank farm with an evapotranspiration (ET) cover with a capillary/biobarrier by 2035, as for Alternatives 2b, 3b, and 4b, would be technically feasible, since infrastructure constraints would have been removed by the decontamination and decommissioning (D&D) program prior to capping. Capping the central tank farm with an ET cover with a capillary/biobarrier by 2012, as for Alternatives 2a, 3a, and 4a, would be less feasible because of infrastructure constraints.

In situ grouting for Alternatives 4a and 4b would have relatively low implementability due to the extensive subsurface infrastructure and technical complexity. Alternative 4b is more technically feasible than Alternative 4a, since infrastructure constraints would be reduced by 2035. CPP-31 soil removal for Alternatives 3a and 3b has the lowest technical implementability due to infrastructure constraints, extensive worker protection requirements, and technical complexity.

Groundwater pumping and treatment implemented under Alternative 5 would be complex but is technically and administratively implementable. The ICDF would not be available for disposal of secondary wastes during the pumping period; however, it was assumed that an equivalent facility would be available when needed.

Summary–Six alternatives (Alternatives 2a, 2b, 3a, 3b, 4a, 4b) would meet the threshold criteria of overall protection of human health and the environment, and compliance with ARARs. The combination of low-permeability asphalt and an ET cover with a capillary/biobarrier implemented for these alternatives would effectively control infiltration, reduce direct radiation exposures to future workers, and prevent biotic intrusion and transport of contaminants to the surface. Removing or immobilizing residual Sr-90 in alluvial soil at CPP-31, as for Alternatives 3a/3b and 4a/4b, respectively; would not significantly improve overall protection of human health and the environment or compliance with ARARs, compared to containment alone, as for Alternatives 2a/2b.

Low-permeability asphalt pavement implemented to control infiltration for Alternatives 2a, 2b, 3a, 3b, 4a, and 4b would require maintenance and periodic replacement until the Sr-90 MCL was attained in the SRPA in about 2129. The ET cover with a capillary/biobarrier implemented for the same alternatives, to control infiltration and protect future workers, would function effectively with no operation and maintenance after 2095, until the worker Cs-137 soil preliminary remediation goal was attained in about 2234.

Alternative 5 would only be implemented after Alternative 2a, 2b, 3a, 3b, 4a, or 4b had already been implemented and had been determined through SRPA monitoring to not be sufficiently protective of the aquifer. Alternative 5, in combination with Alternative 2a, 2b, 3a, 3b, 4a, or 4b, would meet all threshold criteria.

Alternative 1 would meet RAOs I and IV only, by maintaining institutional controls through 2095. Alternative 1 would not meet the Idaho Ground Water Quality Rule or DOE Order 5400.5 "Radiation Protection of the Public and the Environment" after 2095.

None of the alternatives would result in short-term risks to the public or the environment during implementation. Alternatives 3a/3b and 4a/4b, which incorporate source removal or in situ treatment, would have the lowest short-term effectiveness because workers could be exposed to high radiation fields during soil removal or in situ treatment, respectively. Alternatives 2a and 2b would have better short-term effectiveness since relatively lower amounts of lower-activity soil would be excavated, and worker exposures during capping would be relatively low. Worker exposures could occur during operation and maintenance of the groundwater treatment system for Alternative 5, but these could be reduced to allowable levels by engineering and administrative controls. Alternative 1 would have the best short-term effectiveness.

Phased remedy implementation, as for Alternatives 2b, 3b, and 4b, would be much more technically implementable than completing construction of the final remedy by 2012, as for Alternatives 2a, 3a, and 4a. Continuing INTEC operations in and around the tank farm would greatly reduce implementability of a final remedy before 2035, the assumed date when northern INTEC operations will end. Alternatives 2b, 3b, and 4b would be equivalent to Alternatives 2a, 3a, and 4a with respect to threshold criteria but would be much more implementable and would have higher short-term effectiveness.

Total project cost expressed as net present value in FY 2006 dollars, for alternatives that meet the threshold criteria, range from $9.0M for Alternative 2b to $44.5M for the combination of Alternatives 3a and 5.

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CONTENTS

FIGURES

TABLES

ACRONYMS

AFI	Arctic Foundations, Inc.
ALARA	as low as reasonably achievable
AOC	area of contamination
ARAR	applicable or relevant and appropriate requirement
AVES	Air Vacuum Excavation System
bgs	below ground surface
BMEP	best management and engineering practice
BMP	best management practice
BRA	baseline risk assessment
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFLUP	Comprehensive Facility Land Use Plan
COC	contaminant of concern
COPC	contaminant of potential concern
CPP	Chemical Processing Plant
CSM	conceptual site model
D&D	decontamination and decommissioning
DC	direct current
DEQ	Idaho Department of Environmental Quality
DOE	Department of Energy
DOE Idaho	Department of Energy Idaho Operations Office
DOT	Department of Transportation
DQO	data quality objective
EC	environmental checklist
ED	electrodialysis

EDI	electrodeionization
EFC	eutectic freeze crystallization
EPA	Environmental Protection Agency
EPTox	extraction procedure toxicity
ERA	ecological risk assessment
ERT	electrical resistance tomography
ESP	Environmental Surveillance Program
ET	evapotranspiration
ETC	evapotranspiration/capillary
FFA/CO	Federal Facility Agreement and Consent Order
FML	flexible membrane liner
FS	feasibility study
GCL	geocomposite layer
GIS	geographical information system
GPR	ground penetrating radar
GPRS	Global Positioning Radiometric Scanner
GPS	global positioning system
GRA	general response action
GTCC	greater-than-class C
HASP	health and safety plan
HDPE	high-density polyethylene
HEPA	high-efficiency particulate air (filter)
HHRA	human health risk assessment
HI	hazard index
HLW	high-level waste
HSSB	horizontal subsurface barrier

HVAC	heating ventilating, and air conditioning
HWMA	Hazardous Waste Management Act
IC	institutional control
ICDF	Idaho CERCLA Disposal Facility
ICP	Idaho Cleanup Project
IDAPA	Idaho Administrative Procedure Act
ILCR	incremental lifetime cancer risk
INEEL	Idaho National Engineering and Environmental Laboratory
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
ISMS	Integrated Safety Management System
ISV	in situ vitrification
IWTU	Integrated Waste Treatment Unit
IX	ion exchange
LDR	land disposal restriction
LET&D	Liquid Effluent Treatment and Disposal (Facility)
LLRW	low-level radioactive waste
LLW	low-level waste
LTS	Long-Term Stewardship
MCL	maximum contaminant level
MF	microfiltration
MRDS	Monitoring Report/Decision Summary
MSA	management self-assessment
MSIP	Monitoring System Installation Plan
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act

NESHAP	National Emission Standard for Hazardous Air Pollutants
NF	nanofiltration
NLCI	no-longer-contained-in
NOAA	National Oceanographic and Atmospheric Administration
NPL	National Priorities List
NPV	net present value
NSD	notice of soil disturbance
NWCF	New Waste Calcining Facility
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
OU	operable unit
P&ID	piping and instrumentation diagram
PCB	polychlorinated biphenyl
PEW	process equipment waste
PFD	process flow diagram
PLC	programmable logic controller
POTW	publicly owned treatment works
PPE	personal protective equipment
PRCZ	primary recharge control zone
PRG	preliminary remediation goal
R&D	research and development
RA	remedial action
RAO	remedial action objective
RCF	root concentration factor
RCRA	Resource Conservation and Recovery Act
RCT	radiological control technician

RD	remedial design
RES	Remote Excavation System
RG	remediation goal
RI	remedial investigation
RO	reverse osmosis
ROD	Record of Decision
RPO	representative process option
RWMC	Radioactive Waste Management Complex
RWP	radiological work permit
S/S	solidification and stabilization
SBW	sodium-bearing waste
SDA	Subsurface Disposal Area
SITE	Superfund Innovative Technology Evaluation
SRCZ	secondary recharge control zone
SRPA	Snake River Plain Aquifer
SRS	Savannah River Site
STP	Sewage Treatment Plant
SVE	soil vapor extraction
SWLP	solid waste leaching procedure
T&FR	technical and functional requirement
TAN	Test Area North
TBC	to be considered
TCE	trichloroethylene
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TEP	tri-ethyl phosphate

TFIA	Tank Farm Interim Action
TRU	transuranic
TSCF	transpiration stream concentration factor
TSD	treatment, storage, and disposal
TSS	total suspended solids
UCL	upper confidence limit
UF	ultrafiltration
UMTRA	uranium mill tailings remedial action
UTS	Universal Treatment Standards
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UV	ultraviolet
VPP	Voluntary Protection Program
WAC	Waste Acceptance Criteria
WAG	waste area group
WCF	Waste Calcining Facility
WIPP	Waste Isolation Pilot Plant
WTU	water treatment unit
ZVI	zero-valent iron

Operable Unit 3-14 Tank Farm Soil and Groundwater Feasibility Study

1. INTRODUCTION

Operable Unit (OU) 3-14 tank farm soil and groundwater consists of a group of contaminated soil sites located at the Idaho Nuclear Technology and Engineering Center (INTEC) and the groundwater in the Snake River Plain Aquifer (SRPA) affected by INTEC releases. INTEC and the INTEC tank farm are located on the Idaho National Laboratory (INL) Site in southeastern Idaho (Figure 1-1). The tank farm is an integral part of INTEC, which was formerly known as the Chemical Processing Plant (CPP). The CPP was built in 1951 to dissolve spent nuclear fuel removed from reactors to recover the unused uranium-235. Highly radioactive liquid wastes were stored underground in the tank farm, concentrated, and/or solidified. Although the tanks in the tank farm have not leaked, piping and valves have leaked and contaminated soil, perched water, and groundwater. This Feasibility Study (FS) is a companion document to the OU 3-14 Remedial Investigation/Baseline Risk Assessment (RI/BRA) (DOE-NE-ID 2006). The RI/BRA and FS are being conducted pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) under a Federal Facility Agreement and Consent Order (FFA/CO) (DOE-ID 1991) between the Idaho Department of Environmental Quality (DEQ), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Energy (DOE).

The RI/BRA presented the results of investigations into the nature and extent of contamination at OU 3-14 sites and an assessment of the baseline risks to human health and the environment from the contamination. The RI/BRA evaluated the risks from exposure to contaminated tank farm soil. Numerical models were used to predict future contaminant concentrations in the SRPA and evaluate the risks to future hypothetical residents from exposure to the contaminated groundwater. The RI/BRA determined that the OU 3-14 soil sites and the underlying groundwater pose unacceptable risks and require a FS to develop and assess remedial action alternatives.

1.1 Purpose and Objectives

The purpose of this FS is to develop and provide to decision-makers a range of response actions that will protect human health and the environment from the contamination associated with the INTEC tank farm soil and groundwater in the SRPA in the vicinity of INTEC.

1.2 Scope

The scope of this FS is to

1. Further refine the remedial action objectives (RAOs) based on the results of the OU 3-14 RI/BRA for soil inside the tank farm boundary, two sites adjacent to the tank farm, and the SRPA affected by INTEC releases. The RAOs specify the contaminants and media of concern, exposure pathways, receptors, and preliminary remediation goals (PRGs) that permit a range of treatment and containment alternatives to be developed.

2. Further refine chemical- and location-specific applicable or relevant and appropriate requirements (ARARs) and criteria to be considered (TBCs) that were proposed in the RI/BRA and expand them to include action-specific ARARs.

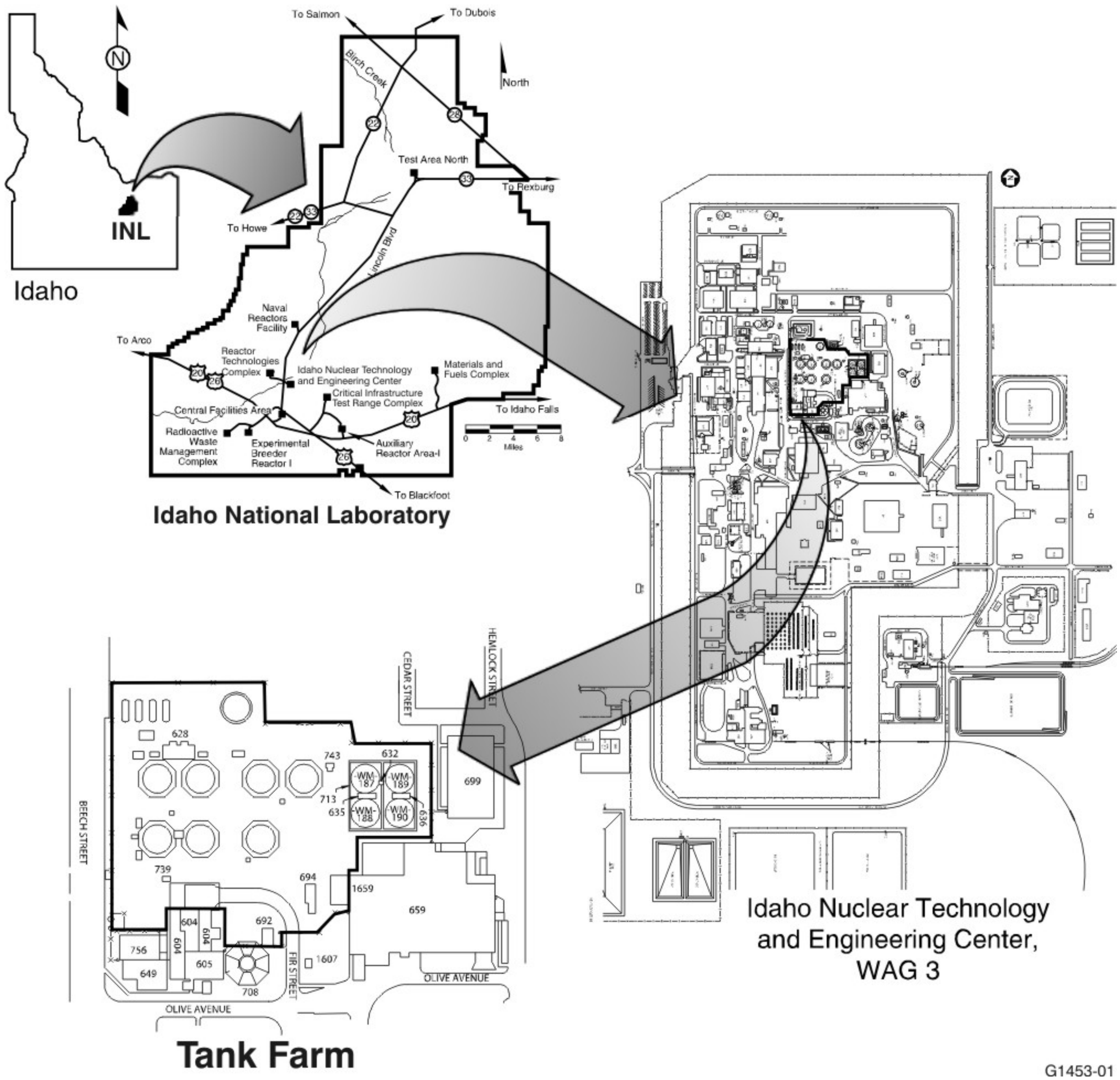

Figure 1-1. Location of the INL Site, INTEC, and the tank farm.

3. Identify general response actions (GRAs) for each medium (soil and the SRPA) that may meet RAOs, either individually or in combination with other GRAs.

4. Identify, screen, and evaluate remedial technology types for each GRA based on technical implementability.

5. Evaluate process options that pass the preliminary screening based on effectiveness, implementability, and relative cost to select one or more representative process options (RPOs) for each technology type.

6. Assemble RPOs into a range of remedial alternatives, from limited action, including institutional controls, to containment, removal, and treatment alternatives.

7. Perform a detailed analysis of potential remedial alternatives to address the contaminants of concern (COCs) and exposure pathways using the CERCLA threshold criteria of protection of human health and the environment and ability to meet ARARs; and the CERCLA balancing criteria of long-term effectiveness and permanence, reduction of toxicity, mobility, and volume through treatment, short-term effectiveness, implementability, and cost.

8. Perform a comparative analysis of the remedial alternatives using the seven evaluation criteria to determine the relative performance of each alternative in relation to each specific evaluation criterion. This identifies the advantages and disadvantages of each alternative relative to one another and the key tradeoffs.

Two additional modifying criteria, state acceptance and community acceptance, will be evaluated following comment on the RI/FS report and Proposed Plan and will be addressed in the Record of Decision (ROD).

1.3 Background Information

OU 3-14 was created to address data gaps that prevented a final remedial action decision for the INTEC tank farm soil and groundwater during the OU 3-13 Comprehensive Remedial Investigation/ Feasibility Study (DOE-ID 1997).

1.3.1 Site Descriptions

The locations of OU 3-14 soil sites at the INTEC are shown on Figure 1-2. Two sites, CPP-15 and CPP-58, are located outside the tank farm boundary adjacent to the southern boundary. The sites and interstitial soil inside the tank farm and the two sites outside the tank farm are collectively known as CPP-96. The regulatory history of these sites up until the OU 3-13 ROD was signed is summarized in Table 1-1. Site CPP-79 (deep) is not included in Table 1-1 because it was identified as a separate source from the shallow CPP-79 site after the OU 3-13 ROD was finalized. To facilitate developing and evaluating remedial actions, the sites have been grouped for the FS:

- Sites that are inside the tank farm boundary not producing significant risks to groundwater from residual contamination currently in the alluvium and potentially accessible only by workers: This includes Sites CPP-16, CPP-20, CPP-24, CPP-25, CPP-26, CPP-27, CPP-28, CPP-30, CPP-31, CPP-32, CPP-33, CPP-58W, CPP-79, and CPP-79 (deep) and the contaminated backfill from construction activities located between these sites. Site CPP-31 was caused by a 1972 leak of approximately 18,600 gal of sodium-bearing waste during a transfer of waste between two underground storage tanks. Because the historical leak at Site CPP-31 is the source of over 87% of the total Cs-137, Sr-90, and Tc-99 released at the OU 3-14 sites, the FS also considers remedies specifically for Site CPP-31 by itself. An estimated 16,700 curies (Ci) of Cs-137, 15,900 Ci of Sr-90, and 3 Ci of Tc-99 were leaked at this site. Detailed descriptions of the leaks and spills, nature and extent of contamination, and previous cleanup activities for all of the tank farm sites can be found in Section 5 of the RI/BRA (DOE-NE-ID 2006). Cs-137 and Sr-90 are the primary risk drivers.

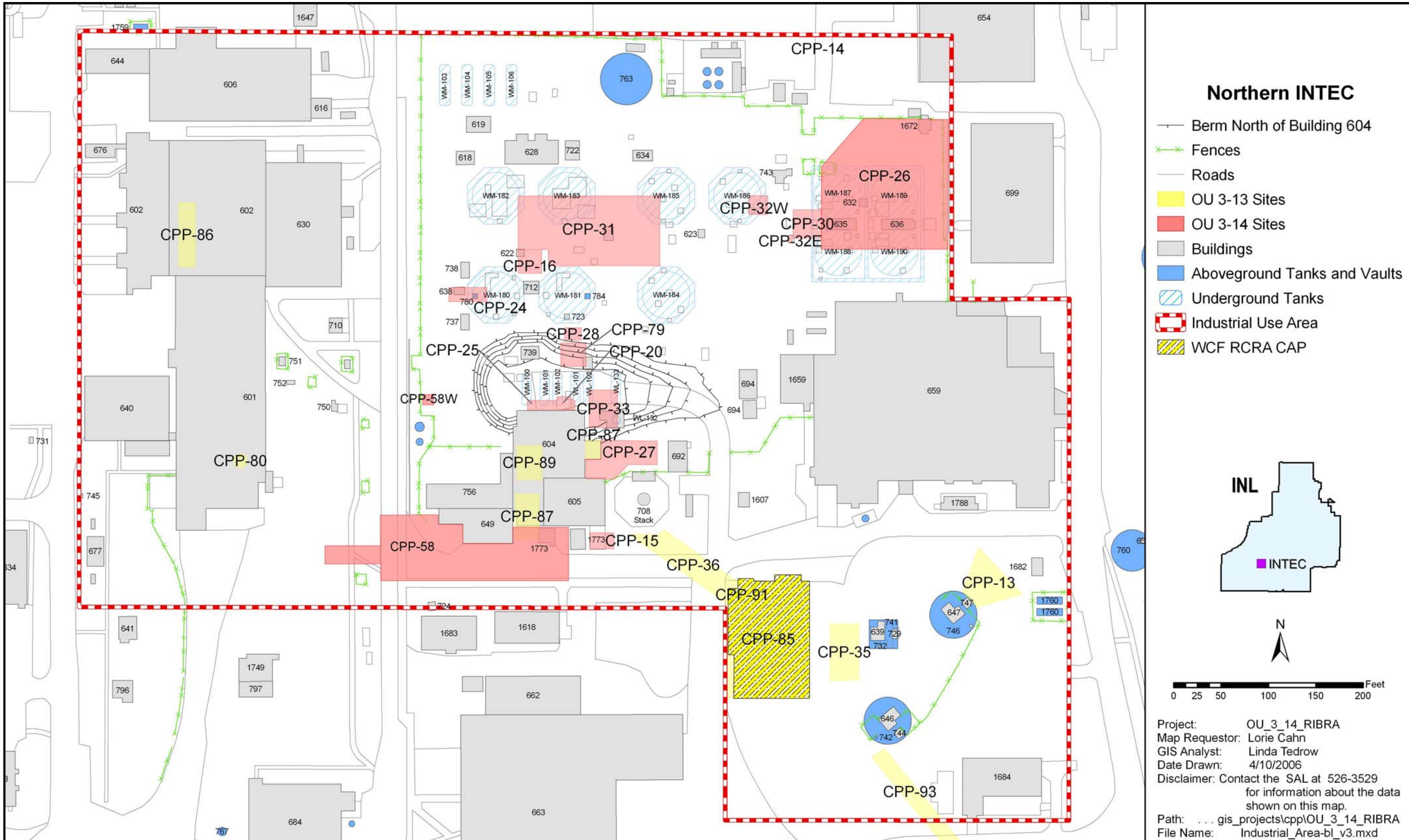

Figure 1-2. Map of northern INTEC, OU 3-14 and 3-13 soil sites, and industrial use area.

Table 1-1. OU 3-14 CPP release sites description and regulatory history.

Site	Original Operable Unit	Cause and Location of Contaminated Soil	Site Group	OU 3-13 ROD Decision
CPP-15	OU 3-08	Overflow of stack condensate and solvent from solvent burner tank flange. Located southeast of CPP-605.	1	OU 3-14 RD/RA
CPP-16	OU 3-07	Leak of contaminated service wastewater and sodium-bearing waste from valve in an unlined valve box between WM-181 and process equipment waste (PEW) evaporator. Located northwest of WM-181.	1	OU 3-14 RD/RA[a]
CPP-20	OU 3-07	Leaks of low-activity, off-Site waste from tanker truck hose connections. Located on berm north of CPP-604.	1	OU 3-14 RD/RA
CPP-24	OU 3-07	Bucket of contaminated off-gas condensate collected in WM-180 and dumped onto ground. Located west of WM-180.	1	OU 3-14 RD/RA[a]
CPP-25	OU 3-07	Leak from temporary transfer line fittings on transfer line from WM-181 to PEW evaporator. Located north of CPP-604.	1	OU 3-14 RD/RA
CPP-26	OU 3-07	Leak from waste transfer line during decontamination activities (steam flushing) while preparing to make new connections to transfer lines. Located primarily northeast of CPP-635.	1	OU 3-14 RD/RA
CPP-27	OU 3-08	Leak of Waste Calcining Facility (WCF) scrub solution from tank farm pressure relief line via connection with waste transfer line between WCF and PEW evaporator. Located east of CPP-604.	1	OU 3-14 RD/RA
CPP-28	OU 3-07	Leak of first-cycle waste from hole in transfer line (construction error) between CPP-601 and tank farm. Located south of WM-181.	1	OU 3-14 RD/RA
CPP-30	OU 3-07	Contamination spread by poor housekeeping during maintenance activities inside valve boxes. Located west of Valve Box B-9.	1	OU 3-14 RD/RA[a]
CPP-31	OU 3-07	Leak of sodium-bearing waste through a valve on an interconnecting line to the waste transfer line between WM-181 and WM-180. Located south of WM-183.	1	OU 3-14 RD/RA
CPP-32	OU 3-07	Leaks from temporary aboveground piping used to remove water from tank vaults (CPP-32W) and contamination from valve box sump sampling activities (CPP-32E). Located southwest and northwest of Valve Box B-4.	1	OU 3-14 RD/RA
CPP-33	OU 3-06	Leak of WCF scrub solution from tank farm pressure relief line via connection with waste transfer line between WCF and PEW evaporator (same source as CPP-27). Located east of CPP-604.	1	OU 3-14 RD/RA

Table 1-1. (continued).

Site	Original Operable Unit	Cause and Location of Contaminated Soil	Site Group	OU 3-13 ROD Decision
CPP-58	OU 3-11	Leaks (3) of PEW evaporator waste from line between CPP-604 and service waste system. Located southwest of CPP-604.	1	OU 3-14 RD/RA
CPP-79	OU 3-07	Leaks (shallow) of low-activity waste from transfer lines between WCF/New Waste Calcining Facility (NWCF) and the PEW evaporator. Leaks (deep) of first-cycle waste in valve boxes and associated tile encasements. Located north of CPP-604.	1	OU 3-14 RD/RA
CPP-96	OU 3-13	Contamination from leaks described above that reside throughout the tank farm as the result of excavation, backfill, and other activities that have spread contamination.	1	OU 3-14 RD/RA

a. No Action sites within the tank farm are consolidated into Site CPP-96. Because the sites are within the tank farm, they will be subject to the Group 1 Interim Action and to the OU 3-14 RI/FS.

- Sites outside the tank farm boundary not producing significant risks to groundwater from residual contamination in the alluvium and potentially accessible to workers:

  - CPP-15 – Site CPP-15 is located just outside the tank farm boundary, near the former solvent burner. In March 1974, an estimated 1,000 L each of condensate from the main INTEC stack and waste organic solution (kerosene) spilled onto the ground. The bulk of the contamination was removed in 1974 and during the removal of the solvent burner and organic storage tank in the mid-1980s. In 1995, during excavation to install a transformer pad and electrical duct bank over the site, workers encountered contaminated soil and the concrete footer from the old stack preheater. The workers were instructed to remove the footer and contaminated soil to approximately 10 ft or clean soil, whichever came first, and backfill the site. Soil that was uncontaminated based upon field screening was stockpiled and used as backfill; however, under CERCLA the soil does not meet current occupational cleanup standards but does meet cleanup standards for future workers. The site is currently covered by the transformer pad, transformers, and the electrical duct bank. These electrical utilities are anticipated to be required until the INTEC facility is closed and deactivated, decontaminated, and decommissioned.

  - CPP-58 – Soil at Site CPP-58 was contaminated by separate releases in 1976, 1977, and 1980 from piping containing PEW evaporator overheads. It also includes a nitric acid spill discovered in 2001, which covered an area approximately 1.5 ft in diameter. The soil does not meet current occupational cleanup standards but does meet cleanup standards for future workers.

- INTEC groundwater – INTEC groundwater is predicted to exceed State of Idaho groundwater quality standards for strontium-90 until the year 2129. The primary source of the future groundwater contamination is strontium-90 that has migrated to the perched water.

1.3.2 Site Regulatory Background

A CERCLA comprehensive RI/FS was previously completed for OU 3-13, which consisted of all the known contaminant release sites at INTEC in 1997, including the perched water and groundwater. Ninety-five release sites were evaluated in the remedial investigation, 40 of which exceeded the soil RAOs and were further evaluated for remedial alternatives in the FS. The sites for remedial action were divided into seven groups and included Tank Farm Soils (Group 1), Perched Water (Group 4), and the Snake River Plain Aquifer (Group 5).

Data gaps and uncertainties associated with contaminant source estimates, the extent of contamination, potential releases from the tank farm soil, and site risk prevented the Agencies from reaching a final remedial decision on the former INTEC injection well, groundwater inside the INTEC security fence, and the tank farm soil. As a result, the Agencies created OU 3-14 to address the final action for tank farm soil and groundwater while interim actions are being implemented under the OU 3-13 ROD, which was signed in October 1999. The interim actions are designed to control the principal threat wastes at the tank farm site due to direct radiation exposure and leaching and transport of contaminants to the perched water and the SRPA. The interim actions will be in place until the final remedy for these sites is selected and implemented as part of the OU 3-14 process.

The ROD for OU 3-13 (a) selected an interim remedy for the tank farm soil and INTEC groundwater inside the INTEC security fence; (b) established OU 3-14 to further characterize the tank farm soil and groundwater and coordinate the final remedial action with activities of other programs that are responsible for treating tank waste and closing the tanks; and (c) selected a final action for the remaining sites, including perched water and groundwater outside the INTEC security fence.

An Explanation of Significant Differences for OU 3-13, which was signed by the Agencies in 2004, transferred the former INTEC injection well and three No Action sites from OU 3-14 back to OU 3-13 and finalized the No Action decision for these sites (DOE-ID 2004).

Two of the remaining OU 3-14 sites are located adjacent to the tank farm (CPP-15 and CPP-58). The rest of the OU 3-14 soil sites are located within the tank farm. All of the OU 3-14 soil sites were consolidated into a single site (CPP-96), which includes the contaminated backfill between the tank farm sites.

Because a comprehensive RI/BRA and FS were already completed for the tank farm soil and groundwater under OU 3-13, the OU 3-14 RI/BRA and FS are focused investigations. The OU 3-14 RI/BRA was designed to address specific data gaps from OU 3-13 that prevented a final decision in the OU 3-13 ROD. This focused study was based upon past information developed under OU 3-13 and included updated information that had been gathered for the tank farm soil under OU 3-14 and for groundwater and perched water under OU 3-13 remedial actions that were put in place when the ROD was signed in 1999.

Perched water and aquifer monitoring at INTEC is being performed under OU 3-13 Group 4 (perched water) and Group 5 (groundwater). Although investigations into the physical and chemical nature and extent of contamination in the perched water and groundwater are not part of the scope of OU 3-14, a final decision for the SRPA will be made under OU 3-14. Because a final remedy for perched water was selected and is being implemented under the OU 3-13 ROD, perched water is not part of the scope of OU 3-14. Therefore, this FS does not screen technologies for perched water. However, because perched water can transport contamination to the groundwater, additional modeling runs were conducted during the FS to evaluate the effectiveness of the additional actions to control recharge to perched water, and the results of these runs are included. Remedies are formulated in the OU 3-14 FS to address actions on the soil and groundwater, and those that would control and reduce recharge to the perched water.

The OU 3-14 tank farm soil and groundwater FS has unusual regulatory elements because its objective is to provide information needed to select a remedy for a CERCLA site that is collocated within an operating Resource Conservation and Recovery Act (RCRA) facility. The closure of the tanks is being performed in phases in accordance with an Idaho Hazardous Waste Management Act (HWMA)/RCRA closure plan that is prepared for each phase. The final closure of the tank farm will be complete when all of the tanks and ancillary equipment have been closed, including performing any postclosure requirements. A decision to close the unit as a landfill or as a RCRA/HWMA clean closure will be determined during final closure. DOE must cease use of the tanks (emptied to the heels) by December 31, 2012.

1.3.3 Land Use

The INL Site is located in southeastern Idaho and occupies 890 mi^2 in the northeastern region of the Snake River Plain. Regionally, the INL Site is nearest to the cities of Idaho Falls and Pocatello and to U.S. Interstate Highways I-15 and I-86. The INL Site extends nearly 63 km (39 mi) from north to south and is about 58 km (36 mi) wide in its broadest southern portion. DOE administers land within the INL Site. Access to the INTEC and tank farm are controlled.

The *Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement* discusses current land use plans that include a 100-year institutional control period for INTEC (DOE 2002). INTEC has an established industrial infrastructure, a portion of which is shown on Figure 1-2. In addition, the RCRA closure of the Tank Farm Facility, which includes eleven 300,000-gal tanks; four 30,000-gal tanks; piping; and infrastructure, such as valve boxes, will be cleaned and grouted in place. The WCF, located to the southeast of the tank farm, has been grouted in place and closed as a RCRA landfill. Other nearby facilities, such as the NWCF, Building CPP-659, bin sets where calcined waste is stored (shown as blue circles in southeastern portion of Figure 1-2), and Fuel Reprocessing Complex (Buildings CPP-601 and CPP-602) may be difficult to clean up to free-release criteria. The Agencies have agreed that future residential use over these facilities and tanks is not a reasonable future use scenario. The industrial use area, which is shown on Figure 1-2, includes the permanent barrier systems (WCF RCRA cap and tanks to be grouted) and these other facilities. The extent of a permanent industrial use area extends from bin sets in the southeast, to the NWCF in the east, the tank farm and to-be-grouted 30,000-gal tanks to the north, the Fuel Reprocessing Complex on the west, and the grouted WCF to the south.

1.3.4 Environmental Setting and Summary of Subsurface Water Contamination

The INL Site is located on the Snake River Plain, which is a large flat valley surrounded by mountains. Air masses crossing this mountain barrier lose most of their moisture before entering the Snake River Plain. Because of this rain shadow effect, the INL Site receives only about 8.6 in. of average annual precipitation, and the region is classified as semiarid.

The United States Geological Survey and DOE have drilled and sampled the INTEC subsurface extensively in an effort to understand and monitor the movement of groundwater and contaminants. To date, over 120 wells have been drilled at and around INTEC. Approximately 47 of these wells were drilled to depths that penetrate into the SRPA; approximately 73 of the wells are completed in the vadose zone to monitor the various perched water bodies beneath INTEC; and numerous holes have been drilled at INTEC in the surficial sediments to the top of the basalt.

The depth to basalt in the tank farm ranges from approximately 40 ft to 60 ft in areas where basalt was removed during construction of the first two tank vaults. Most of the alluvial material in the tank farm area was removed during installation of the underground tank farm and replaced as backfill. The movement of water and contaminants within the tank farm alluvium (referred to as soil) is therefore more likely controlled by construction-related layering than any original stratigraphy. Besides the fill materials that were used in the tank farm, the infrastructure (piping, valve boxes, tank vaults, etc.) also controls contaminant movement.

The tank farm alluvium is underlain by thick sequences of basalt flows separated by thin sedimentary interbeds deposited at the former land surfaces during the intervening periods between volcanic eruptions. Infiltrating water from precipitation, the Big Lost River, which flows intermittently past the northwest corner of INTEC, and process water have created discontinuous perched water zones. The perched water is contaminated from sources that originated from INTEC activities and from the former INTEC aquifer injection well, which failed and caused contamination in the deep vadose zone.

The SRPA is approximately 460 ft below the tank farm although depth to water is greater during drought conditions. The SRPA is among the nation's most productive aquifers. It is also contaminated from INTEC activities, including the former injection well (strontium-90 and iodine-129) and tank farm waste that leaked to the soil, migrated to the underlying perched water, and, in the case of technetium-99 and nitrate, migrated to the aquifer. The SRPA beneath INTEC currently exceeds the Idaho Ground Water Quality standard (equivalent to the federal drinking water standard, or maximum contaminant level [MCL]) in one or more monitoring wells for technetium-99, iodine-129, and nitrate as nitrogen, which are very mobile, and strontium-90, which is less mobile. The monitoring wells are not used for drinking water, and comparison with MCLs is for reference only.

Technetium-99 exceeds the MCL of 900 pCi/L in two aquifer monitoring wells, one just north of the tank farm (approximately three times the drinking water MCL) and one to the southeast, both of which are upgradient from the injection well. In 2005, one monitoring well near the tank farm slightly exceeded the nitrate as nitrogen MCL of 10 mg/L. The 1972 leak at OU 3-14 Site CPP-31 is likely the primary source of this technetium-99 and nitrate contamination.

In 2005, one aquifer monitoring well slightly exceeded the I-129 MCL of 1 pCi/L. The strontium-90 plume in the aquifer that exceeds the drinking water MCL of 8 pCi/L is more extensive, extends about a mile past the former injection well, and appears to be shrinking. The primary source of the Sr-90 contamination currently in the SRPA was waste that was injected directly into the aquifer in the former injection well. The injection well casing had corroded and waste was also injected into the deep vadose zone. The injection well has been plugged and abandoned. However, a much larger source of Sr-90 was released at Site CPP-31 and other tank farm sites, has migrated to the underlying perched water, and has the potential to migrate to the SRPA. Shallow perched water under the tank farm that is on top of the 110-ft interbed is contaminated with Sr-90 at a maximum concentration of approximately 180,000 pCi/L.

1.3.5 Nature and Extent of Soil Contamination

Although none of the tanks in the tank farm have ever leaked, some of the ancillary piping and valves and activities, such as maintenance and sampling, released wastes that contaminated sites in the tank farm. The waste stored in the INTEC tank farm came from reprocessing spent nuclear fuel and related activities, such as equipment decontamination, uranium purification, laboratory work, off-gas treatment, fuel receipt and storage, and waste solidification. The major sources of tank farm waste were concentrated by-products from the uranium extraction and purification processes and evaporator concentrate. Some of the leaks that contaminated soil were a result of flaws in piping or valve designs.

Several major tank farm upgrade projects over the years have improved and replaced inferior designs. The contamination at the OU 3-14 soil sites occurred between 1954 and 1986. Information on tank farm historical activities is used to determine the volume and composition of the wastes that leaked. Because the tank farm is an operating facility, OU 3-14 activities are integrated with, and limited by, ongoing tank farm closure activities and operations. For example, active waste transfer lines run through the center of the primary OU 3-14 site, and probing and drilling into the subsurface at this site are constrained.

An investigation into the nature and extent of contamination for each OU 3-14 site was performed. An extensive search of historical operational records and reports was conducted, and personnel intimately familiar with tank farm operations, history, and process knowledge reviewed these records. A conceptual model of each spill or leak and an estimate of the volume and composition of the contaminated liquid released were developed. Additional probing and soil sampling in the tank farm were performed in 2004 at five sites to resolve identified data gaps. Historical and new soil concentration data were evaluated to support and/or refine the conceptual model of releases at each site. The data are also used to determine exposure concentrations in the soil for use in the risk assessment. Information on the releases was used to develop a reasonably conservative source term with which to calibrate the groundwater fate and transport model and predict future concentrations of contaminants in the aquifer.

Approximately 18,100 curies of strontium-90, 19,100 curies of cesium-137, and 3.56 Ci of technetium-99 are estimated to have been released to OU 3-14 soil. The 1972 leak at Site CPP-31 is the major release from the tank farm and occurred when approximately 18,600 gal of waste leaked during transfer from one tank to another. The liquid (called sodium-bearing waste) was primarily evaporator concentrate and contained approximately 800 mCi/gal of strontium-90. The leak at CPP-31 accounts for more than 87% of the strontium-90 and cesium-137, and 89% of the technetium-99 released at the OU 3-14 sites. Three other sites (CPP-28, CPP-27/33, and CPP-79 [deep]) account for 12% of the strontium-90 and 10.7% of the technetium-99. All other OU 3-14 sites account for less than 0.05% of the strontium-90 and technetium-99.

Sampling data collected in 2004 were used, along with historical records and photos, to determine the extent of contaminated backfill reused in the tank farm. Sources of material used as backfill in the tank farm vary both in location and concentration. Borrow material came from different locations both inside and outside the tank farm depending on what was available at the time. Some of the backfill in the tank farm was contaminated and some was from clean borrow sources. Estimating the amount and location of the contaminated backfill contained within and between the OU 3-14 sites inside the tank farm boundary is not possible due to the lack of complete historical records detailing the location of contaminated backfill and estimates of contamination levels. In addition, some historical excavations used slightly contaminated soil as backfill because the radioactivity levels were undetectable by field instrumentation used at the time and the soil would have been deemed “clean” backfill. Their final location and volumes are unknown. The OU 3-14 investigation determined that contaminated soil from the original soil sites inside the tank farm boundary was not confined to these site boundaries during major tank farm excavation projects, and a site that was No Action under OU 3-13 based on the historical release could have had contaminated soil placed in the site during any number of construction activities through the site. Therefore, the RI/BRA grouped all of the soil inside the tank farm boundary including the three former No Action sites (CPP-16, CPP-24, and CPP-30) for the purposes of assessing risk.

1.3.6 OU 3-13 Group 4 (Perched Water) Remedy

Perched water exists at several depths within the 460-ft-thick vadose zone beneath INTEC. Since the 1950s, perched water levels and water quality have been monitored to assess the downward migration of radionuclides and other contaminants toward the aquifer. These investigations have revealed that Sr-90 is the contaminant in perched water that represents the greatest threat to groundwater quality in the underlying SRPA (DOE-NE-ID 2006).

Under the CERCLA program, perched water is regulated under OU 3-13 and is therefore not specifically included as part of the OU 3-14 RI/FS. However, actions to control recharge to reduce perched water are considered under OU 3-14. The OU 3-13 ROD (DOE-ID 1999) specified the following remediation goals for perched water (Group 4):

1. Reduce recharge to the perched zones

2. Minimize migration of contaminants to the SRPA, so that SRPA groundwater outside of the current INTEC security fence meets the applicable State of Idaho groundwater standards by 2095.

The final remedy selected for perched water (Group 4) was institutional controls with aquifer recharge control (DOE-ID 1999). Remedial actions specified in the ROD to control surface water recharge to perched water beneath INTEC were

- Relocate percolation ponds (away from INTEC) by December 2003 (Phase 1 remedial action)

- Measure moisture content and COC concentration(s) in the perched water zones to determine if water contents and contaminant fluxes are decreasing as predicted (Phase 1 remedial action)

- Implement additional infiltration controls (Phase 2 to Group 4 remedy) if recession of perched water does not occur within 5 years of removing the percolation ponds, including

  - Line Big Lost River channel segment (if necessary)

  - Minimize recharge to the perched water from lawn irrigation (if necessary).

As of October 2005, the following remedial actions had been completed as part of the OU 3-13 Group 4 remedy:

- Additional monitoring wells were installed in 2001 and 2005.

- A vadose zone tracer study was performed in 2001.

- Perched water levels and moisture contents have been monitored monthly during 2003-2005, and selected perched water wells are equipped with downhole pressure transducers and data loggers for automated water level monitoring. In addition, moisture monitoring of the vadose zone has been performed using downhole advanced tensiometers equipped with data loggers.

- Contaminant concentrations in the perched water have been monitored annually during 2003-2005, and the OU 3-13 vadose zone model updated to reflect recent field data.

- The former INTEC percolation ponds were removed from service and replaced with new percolation ponds 2 miles west of INTEC on August 26, 2002.

- An INTEC water system engineering study performed in 2003 summarized existing information regarding facility water flows. As a result, water metering upgrades were completed in 2004, and water balance calculations for INTEC are being performed annually.

- Lawn irrigation at INTEC has been reduced, and the area of irrigated grass lawns was approximately 1.2 acres as of the end of FY-05.

- On December 4, 2004, the treated wastewater effluent was redirected to the service waste pipeline that flows to the new percolation ponds, and the infiltration trenches at the Sewage Treatment Plant (sewage treatment lagoons) and infiltration galleries were decommissioned and backfilled.

- Upgrades were completed to surface water drainage systems during 2003-04 as part of the Tank Farm Interim Action project. The upgrades included installation of concrete-lined ditches and construction of a lined evaporation pond outside the eastern INTEC fence line.

- Several leaks in underground water lines have been located and repaired during 2004-2005.

- The INTEC vadose zone model was updated in 2005 to better match recent data.

The OU 3-13, Group 4 Monitoring System and Installation Plan (MSIP) (DOE-ID 2005) provides the data quality objectives and schedule for the Group 4 perched water remedial action. The OU 3-13 ROD allows 5 years following completion of the remedial action (relocation of former percolation ponds) before judging the effectiveness of the remedy. According to the MSIP, the Group 4 Monitoring Report/Decision Summary (MRDS) is due on April 21, 2008. However, current plans are to accelerate the MRDS. This primary document will serve as the remedial action report for perched water remediation. The MRDS will assess the efficacy of the perched water remedy and may propose additional actions to reduce the rates of contaminant migration toward the aquifer, if necessary.

1.3.7 Introduction to Risk Assessment and Conceptual Site Model

A conceptual site model was developed for the OU 3-14 BRA to identify the contaminant sources and release mechanisms, exposure pathways, exposure routes, and classes of receptors (Figure 1-3). Two primary sources exist—the tank farm system and the former injection well. Leaks and spills from the tank farm piping and valves resulted in contaminated soil sources. Human exposures to these contaminants can occur primarily by direct contact with surface soil at the spill sites, or the contaminants can be transported by infiltration of water and subsequent leaching. The primary potential human exposure routes include gamma-emitting radionuclides in the soil (direct exposure) and ingestion of contaminated groundwater. Along with contaminated soil, the former injection well contributes to the groundwater exposure pathway and the groundwater ingestion exposure route. The classes of receptors evaluated in this risk assessment are occupational workers (both current time period and 100 years in the future) and hypothetical future residents that may occupy areas outside the industrial use area and drill a well into contaminated groundwater.

1.3.8 Summary of the Soil Risk Assessment

A focused risk assessment for exposure to contaminated soil was conducted because a risk assessment was previously completed under OU 3-13. Because of the mixing of surface soil during tank farm construction projects, all sampling data were pooled for Soil Inside the Tank Farm Boundary for evaluation of surface soil risk from the top 4 ft. Grouping sites within the tank farm boundary is reasonable because it is improbable that a worker would remain over any single site for the duration of the exposure scenario (40 hours per week, 50 weeks per year, for 25 years). The RI/BRA concluded that the soil inside the tank farm boundary poses an unacceptable risk (greater than 1 in 10,000 of developing an excess cancer) to unprotected workers from external exposure to Cs-137. Two sites adjacent to the tank farm, Sites CPP-15 and CPP-58, would pose an unacceptable risk to current workers from external

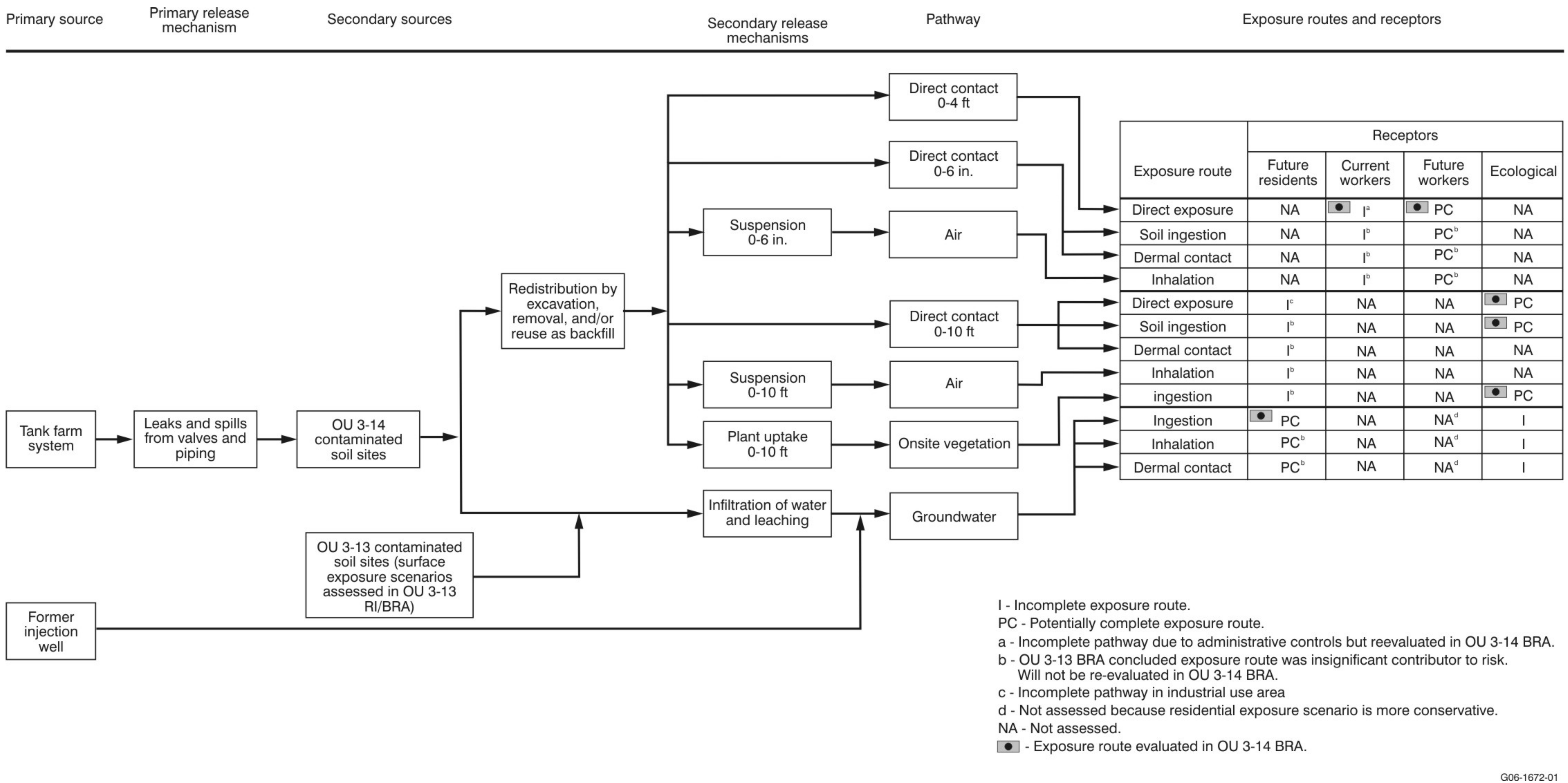

Figure 1-3. OU 3-14 conceptual site model showing groundwater source term and OU 3-14 and OU 3-13 contributing sources.

exposure to Cs-137 within the top 4 ft if there were no administrative controls in place to protect workers. The BRA is unrealistic because it assumes that (1) the worker spends 40 hours per week, 50 weeks out of the year, for 25 years at the individual site, which is relatively small, (2) the contaminated soil at CPP-15 is exposed at the surface, and (3) no administrative controls to protect workers are in place. In reality, none of these assumptions are true, and the workers at CPP-15 are even better shielded from gamma radiation because the site is covered by a transformer pad, transformers, and an electrical duct bank. The Cs-137 contamination will decay to acceptable levels before 2095, when the future occupational scenario would start.

The results of the risk assessment are summarized in Table 1-2. All risk scenarios except risk to future workers from the CPP-15 and CPP-58 sites were unacceptable due to external exposure to cesium-contaminated soil and exceeded the upper end of the target risk range under CERCLA of 1 in 10,000. The other contaminants and exposure pathways were insignificant contributors to risk (much less than a 1 in 1,000,000 risk of excess cancer).

An assessment of ecological risk was previously conducted and was updated with new information.

Table 1-2. Human health contaminants of concern summary (soil).

Site	Contaminant	Risk to Current Worker (2005)	Risk to Future Worker (2095)	Primary Exposure Pathway
Soil Inside Tank Farm Boundary	Cesium-137	**2E-02**[a]	**3E-03**	External exposure
CPP-15	Cesium-137	**7E-04**	8E-05	External exposure
CPP-58	Cesium-137	**4E-04**	5E-05	External exposure

a. **Bold** = Exceeds 1E-04 risk-based level.

1.3.9 Summary of Groundwater Modeling

An extensive screening of contaminants had been performed previously in the OU 3-13 RI/BRA (DOE-ID 1997) to determine contaminants of potential concern (COPCs). To predict future groundwater concentrations and assess risks to hypothetical future residents living outside the industrial use area, a groundwater model had been developed under OU 3-13 using the compute code TETRAD. OU 3-13 modeling predicted that I-129 would exceed Idaho groundwater quality standards beyond the year 2095, primarily from direct injection into the aquifer and also from rapid transport down from the tank farm soil. In 1999, a remedy was selected for the SRPA outside the INTEC fence that involved monitoring in, and contingent pumping and treating of, the aquifer (DOE-ID 1999). Additional well drilling and monitoring have determined that I-129 concentrations are well below predicted concentrations and below the action levels in the aquifer, so the contingent remedy has not been implemented. An interim action of monitoring was selected in OU 3-13 for the SRPA inside the INTEC fence.

Sr-90 had been predicted by the OU 3-13 model to pose an unacceptable risk to groundwater from downward migration through the perched water. Because Sr-90 is retarded as it moves through the soil and interbeds, in 1999 the selected remedy for perched water (recharge control) and the Tank Farm Interim Action (surface water control) was assumed to prevent downward migration of Sr-90 to the SRPA at concentrations that would result in the aquifer exceeding drinking water standards outside the INTEC fence.

A final remedial action decision for the SRPA contaminated by INTEC CERCLA sources inside and outside the INTEC fence must be made under OU 3-14. The groundwater model was updated in the OU 3-14 RI/BRA to try to account for the following observations:

1. The relocation of the former percolation ponds just south of INTEC did not affect the perched water under the tank farm in northern INTEC as had been predicted by the OU 3-13 model.

2. In general, the perched water was not receding everywhere even though surface water and recharge controls were implemented and the Big Lost River did not flow during drought years.

3. The OU 3-13 model overpredicted iodine-129 concentrations in the SRPA and underpredicted technetium-99 concentrations in the SRPA.

4. Most of the source terms in the OU 3-13 RI/BRA and model were overestimated, although some were underestimated.

To assess risks to hypothetical future residents from the SRPA, several numerical models were used to predict future transport of contaminants from all INTEC CERCLA sources through the vadose zone to the SRPA. Because the OU 3-13 model overestimated many of the contaminant source terms and the data collected since the OU 3-13 RI/BRA (DOE-ID 1997) indicated that the model was overpredicting many COCs, including I-129, and underpredicting technetium-99, the OU 3-14 contaminant source terms and some of the larger OU 3-13 source terms were reevaluated under OU 3-14 to determine reasonable, but conservative, values.

The OU 3-13 COPC list was used as the starting point for the OU 3-14 screening process. The list was reviewed using process knowledge, new data collected since the OU 3-13 RI/BRA, or stakeholder concerns to determine if any additional COPCs from the OU 3-13 tank farm sites needed to be added to the list. The computer code, GWSCREEN, was used to screen the COPC list. If the COPC was predicted to have a dose or concentration greater than 1/10 of the drinking water standard, it was retained for further analysis. The list of COPCs, their radioactive progeny, and the results of the screening are in Table 8-2 of Appendix A of the OU 3-14 RI/BRA (DOE-NE-ID 2006). COPCs that were screened out are Am-241, C-14, Co-60, Cs-137, Pu-236, Pu-238, Pu-241, Pu-242, Pu-244, U-232, U-233, U-235, U-236, U-238, Cr, and As. Ten COPCs, H-3, I-129, Np-237, Pu-239, Pu-240, Sr-90, Tc-99, U-234, Hg, and nitrate were retained and simulated with the vadose zone and aquifer models.

Modeling was conducted to simulate release and migration of contaminants from all of the contaminated sites in OU 3-13 and OU 3-14, including the former injection well, and to estimate future contaminant concentrations in the SRPA. The main numerical code was the same one used in OU 3-13 (the TETRAD simulator). The model was updated with new information, and the subsurface structure was represented using geostatistics, rather than combining interbeds. This modification to the model allows for holes in the interbeds to be included in the simulations to better reflect the observation that discontinuing discharges to the former percolation ponds had no effect on perched water levels in northern INTEC under the tank farm. Model parameters to describe contaminant migration, such as partition coefficients, were defined using site-specific information. Reasonable values from the literature were selected when site-specific data were not available. However, the preliminary model calibration to the recommended strontium-90 partition coefficient (K_d) was poor. Model calibration to perched water and groundwater monitoring data was difficult because measurements to provide adequate targets for calibration were insufficient. Contaminants of particular interest for model calibration, such as strontium-90, tritium, technetium-99, and iodine-129, have been monitored sporadically, and the historical record often did not begin until after the contaminant had reached the perched water or aquifer.

The contaminant fate and transport model was very sensitive to the assumptions made regarding the release mechanism for Sr-90 at Site CPP-31. Because of the unique geochemical nature of the release of sodium-bearing waste at CPP-31 (e.g., high sodium and nitrate content, low pH, rapidly changing geochemical conditions), a K_d modeling approach for Sr-90 behavior at this site did not provide an adequate match between observed and simulated behavior. In an attempt to better calibrate the model and gain a better understanding of the influence of rapidly changing geochemical conditions on Sr-90 transport, a geochemical model (TOUGHREACT) in the alluvium was developed. Sr-90 fluxes out of the alluvium for the first 20 years after the release were used as input to the TETRAD model as well as a model-calculated cation exchange capacity (CEC) -based K_d for the alluvium after 20 years.

Using the coupled geochemical/fate and transport model, predicted transport of Sr-90 out of the alluvium into the underlying vadose zone in the first 5 years following the leak at CPP-31 is sensitive to the CEC in the alluvium. The lower the CEC value, the more Sr-90 mass that is released early and the less that remains in the alluvium. However, the predicted risk to the SRPA from the Sr-90 that was released early is not very sensitive to the measured range in CEC values on representative gravels in and around INTEC. Previously collected data on the CEC of the alluvium indicates that the CEC is likely on the low end. Confidence with these data is relatively high. However, many other parameters affect the model predictions and the uncertainty associated with these parameters can be high. The model is particularly sensitive to the amount and location of water assumed to be leaking from INTEC facilities and the K_d in the interbeds.

Groundwater modeling results are summarized on Table 1-3 and include the Idaho groundwater quality standard, the year that the contaminant is predicted to peak in the aquifer, and the maximum predicted concentration in 2095. Strontium-90 concentrations, which currently exceed the drinking water standard, are predicted by the model to slowly decline over time. Modeling predicts that the SRPA will continue to exceed Idaho groundwater quality standards however, until beyond the year 2129 if no additional remedial actions are taken on perched water, the interbeds, alluvium, and/or the tank farm surface. The single largest known source of Sr-90 is the historical release at tank farm Site CPP-31 (15,900 Ci), which accounts for over 87% of the Sr-90 that was leaked or spilled to the alluvium from OU 3-14 tank farm sites (18,100 Ci). This is a large amount of Sr-90, particularly in contrast to the estimated 16 Ci disposed of down the injection well, which created the current Sr-90 plume in the aquifer.

The model overpredicts Sr-90 concentrations in the aquifer. The maximum concentration predicted by the model for the year 2005 is about 1.4 times higher than the current measured peak value. The modeling predicts that the Sr-90 plume will reach its maximum extent prior to the year 2095 and be receding and the 8-pCi/L isopleth will be confined to approximately the southern half of the INTEC fenced area by 2095. The predicted persistence of the Sr-90 plume is the result of multiple sources of Sr-90; however, the uncertainty is large regarding the mass distribution of Sr-90 between the tank farm alluvium, perched water, interbeds, and the deep vadose zone. Before the former INTEC injection well was permanently plugged and abandoned, it failed, which forced Sr-90 contamination out into the deep vadose zone. This deep vadose zone contamination is predicted to contribute to the persistence of the Sr-90 plume as Sr-90 migrates down through the deep vadose zone to the SRPA. The model predicts that a small fraction of the strontium-90 contamination higher in the vadose zone will migrate downward through perched water if no additional remedial actions are taken on the perched water, even though most of the strontium will decay and/or is absorbed to interbeds and alluvium. OU 3-13 Group 4 (Perched Water) is assessing the effectiveness of remedies to reduce infiltration through the alluvium (e.g., curtailment of lawn watering) and determining whether additional actions are necessary, such as lining portions of the Big Lost River, which flows intermittently past INTEC. Modeling runs to determine how effective additional Group 4 remedies would be (such as lining the Big Lost River and further

Table 1-3. Human health contaminants of concern summary (groundwater ingestion pathway). Includes all OU 3-13 and OU 3-14 sources.

COPC	MCL (pCi/L)	Year of Simulated SRPA Peak	Peak Simulated SRPA Concentration (pCi/L)	Peak Simulated SRPA Concentration in 2005 (pCi/L)	Peak Simulated SRPA Concentration in 2095 (pCi/L)	Risk to Future Resident (2095)	Year Below MCL
Carcinogens							
H-3	20,000	1965	4.02E+6	9.97E+4	1.23E+2	1E-07	2001
I-129	1	1970	2.26E+1	3.85E+0	9.00E-1	3E-06	2080
Np-237	15	1965	2.71E+1	4.06E+0	4.22E+0	5E-06	1987
Pu-239	15	1960	3.34E-1	1.72E-2	2.07E-3	3E-09	Always
Pu-240	15	1960	1.67E-1	8.61E-3	1.03E-3	3E-09	Always
Sr-90[a]	8	1965	5.11E+3	4.08E+1	**1.86E+1**	2E-05	2129
Tc-99	900	1999	9.35E+2	2.35E+2	9.84E+0	6E-07	1999
U-234	0.03 (mg/L)	1958	5.36E-7 (mg/L)	1.15E-7 (mg/L)	2.34E-7 (mg/L)	2E-06	Always
Total Risk						3E-05	
Noncarcinogens							
Mercury	0.002 (mg/L)	1981	9.67E-3 (mg/L)	5.86E-4 (mg/L)	1.30E-4 (mg/L)	0.01 (hazard quotient)	1993
Nitrate	10 (mg/L)	1993	1.82E+1 (mg/L)	6.20E+0 (mg/L)	2.10E+0 (mg/L)	0.04 (hazard quotient)	1998
Total Hazard Index						0.05	

a. **Bold** exceeds MCLs in 2095.

reductions in anthropogenic water infiltration) are presented in Appendix A of this FS. Section 1.3.6 discusses actions that have been taken to date to reduce perched water and the effectiveness of these actions so far. The Group 4 MRDS, which will determine the effectiveness of the Group 4 remedy and the need for additional action, is currently scheduled for finalization in spring 2008.

With the exception of Sr-90, the model predicted that Idaho groundwater quality standards would not be exceeded in the SRPA beyond the year 2095 even if no remedial actions were taken. The model underpredicted current Tc-99 concentrations at the two aquifer wells that exceed drinking water standards and matched Tc-99 concentrations fairly well throughout the rest of INTEC. The model predicted that the maximum Tc-99 concentration would fall below the MCLs in the year 2000, but the measured concentrations are still above the MCLs.

For noncarcinogens, the model predicted that the maximum concentration occurred in 1981 for mercury and 1993 for nitrate. The model overpredicts the concentrations of these noncarcinogens because measured aquifer concentrations are below simulated values. All wells currently are below the Idaho groundwater quality standard for mercury. One well in 2005 slightly exceeded MCLs for nitrate as nitrogen.

In summary, the revised INTEC groundwater model predicts that, absent any remedial action, all contaminants except Sr-90, will be below Idaho groundwater quality standards by the year 2095. Contaminants that are highly retarded, such as Pu-239 and Pu-240, which also have long half-lives, and mercury, were modeled out to their peak concentration, which was well beyond the year 2095. None of these slow-moving contaminants are predicted to be transported to the SRPA in concentrations that would exceed Idaho groundwater quality standards even at their peak concentration.

1.3.10 Groundwater Risk Assessment

The results of the groundwater risk assessment are presented in Table 1-3. The groundwater currently exceeds MCLs in one or more aquifer monitoring wells for strontium-90, technetium-99, iodine-129, and nitrate measured as nitrogen. However, there are no receptors because workers are provided drinking water from wells located upgradient of INTEC. The groundwater model predicts that strontium-90 concentrations will continue to exceed MCLs beyond the year 2095. Strontium-90 was identified as the primary contaminant from the OU 3-14 tank farm sources that could adversely impact groundwater quality beyond the year 2095. The model predicts that the SRPA will meet drinking water standards before 2095 for all other contaminants from INTEC sources. Although the model underpredicts current technetium-99 concentrations in two aquifer wells (measured concentrations are three times the model prediction), the concentrations are predicted to be 10 times below the MCL before 2095. Assuming that all peak contaminant concentrations occur at the same time, the maximum cumulative risk to a future resident from all carcinogens would be 3E-05. The hazard index is 0.05 for noncarcinogens (mercury and nitrate).

1.3.11 Summary of Ecological Risk Assessment

The ecological risk assessment (ERA) performed in the OU 3-13 RI/FS is presented in Section 28 of DOE-ID (1997). The OU 3-13 ERA follows the approach presented in the *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL* (VanHorn, Hampton, and Morris 1995) and uses the 0 to 10-ft depth for evaluation. The ERA for the Tank Farm Group and the Tank Farm South Group of sites used the values provided by the HHRA for evaluation. The results of this assessment found that several metals and radionuclides are potentially at levels of concern. Because of the availability of new sampling data and updated input parameters and toxicity data as documented in the OU 10-04 Comprehensive RI/FS (DOE-ID 2001) for ecological receptors, these data were reassessed to ensure that the conclusions made in the OU 3-13 RI/FS are still valid.

Initial screening of contaminants was performed. Those COPCs and radionuclides of potential concern that exceeded screening were further evaluated using the approach documented in the OU 10-04 Comprehensive RI/FS (DOE-ID 2001).

Maximum concentrations of nonradionuclides at OU 3-14 sites do not pose unacceptable risks to ecological receptors. Maximum concentrations of radionuclides do not pose unacceptable risk to ecological receptors at CPP-15 and CPP-58. External exposure of ecological receptors to radionuclides is not a concern for soil inside the tank farm boundary; however, internal exposure to radionuclides Cs-137 and Sr-90 within this group of sites could possibly impact ecological receptors (hazard indexes [HIs] up to 400). However, these sites were assessed as if they had freely available habitat for ecological receptors, and this is not the case. These sites are within the tank farm boundary where weed and other controls are used to discourage natural habitat and the sites are covered by asphalt, structures, or gravel.

1.3.12 Cumulative Impacts from Non-CERCLA Residual Sources at INTEC

Cumulative risk is the combined risk from multiple sources. Assessing combined risks from CERCLA and non-CERCLA sources is important to ensure that the cumulative risk does not exceed risk-based levels. If a site by itself does not pose an unacceptable risk, but a receptor could be exposed to another site that by itself is acceptable, then the combined risk might be unacceptable. For sites that already are predicted to exceed risk-based levels, such as the OU 3-14 soil sites, considering the additional risk from other sources does not alter the conclusion that the site will require remediation. Another cumulative impact consideration would be if several sites were cleaned up to an acceptable level, but a receptor could potentially be exposed to these sites and the combined risk would be unacceptable. Therefore, risk assessments from non-CERCLA INTEC sources that are closed or undergoing closure were reviewed to determine if a receptor could be exposed to two or more sites at the same time. This included the risk assessment for the grouted-in-place WCF (Rood, Smith, and Rood 1996) and the performance assessment for the Tank Farm Facility (DOE-ID 2003), which includes the closed tanks, piping, and sand pads. This information is a potentially important consideration in developing remedial action alternatives for the OU 3-14 tank farm soil and groundwater to ensure that the remedy will be protective when cumulative impacts are considered.

Releases associated with non-CERCLA INTEC sources were determined to occur at different times than the duration of the baseline risks for the CERCLA INTEC sources, the peaks did not overlap, and the peak risks from conservative estimates of these sources postclosure will be so low that the cumulative risk will not exceed risk-based levels or MCLs. The tank farm closure program evaluated the risk from the residuals that are predicted to remain in the tanks, piping, and sand pads after the waste is removed and washing, flushing, and grouting occur. The performance assessment modeled the release of radionuclides from the tanks, piping, and sand pads; transport through the environment; and exposure to the public. The performance assessment assumed that the vault would last intact only for 100 years and that all other components (the grout, the stainless-steel tanks, and piping) would last only for 500 years before they disintegrate and expose the cracked grout to infiltrating water. This information was conservative based on corrosion studies on concrete and stainless steel and did not take any credit for the chemical barrier created by the concrete, which would inhibit Sr-90 migration.

The risk assessment for the WCF took credit for the grout placed in the WCF and the concrete cap. The model assumed that the concrete would remain intact for 100 years, after which the concrete would crack and water would freely enter the waste, leach contaminants, and enter the unsaturated zone. No credit is taken for the stainless-steel calciner vessel.

The performance assessment predicted no release of Sr-90 from the tanks, piping, and sand pads for 500 years. The maximum concentration of Sr-90 predicted in the SRPA is 0.01 pCi/L 550 years after tank closure from the sand pads (approximately 2558). The performance assessment also predicted peak Sr-90 concentrations from the tanks at 1.8E-05 pCi/L and from piping at 4.4E-08 pCi/L 1,110 years after closure. The maximum Sr-90 groundwater concentration predicted from the grouted and capped WCF occurs in 1,990 years and is 2.6E-17 pCi/L. The Sr-90 from the tank farm soil will decay to acceptable levels before the Sr-90 is released from the WCF and the tank farm tanks, piping, and sand pads. If these peak risks from non-CERCLA sources were to occur at the same time and place, the concentration would be 0.01 pCi/L, which is far less than the MCL of 8 pCi/L. Cumulative risk from non-CERCLA INTEC sources of Sr-90 that will not reach the SRPA for over 500 years is not a concern for designing a remedial action to meet the MCL for OU 3-14, where MCLs are predicted to be exceeded for approximately 122 years.

The performance assessment for the Tank Farm Facility predicted peak concentrations of Tc-99 in the SRPA of 9.3E-09 pCi/L 150 years after tank closure from the sand pads, and 116 pCi/L from the tanks and 0.27 pCi/L from the piping 14,600 years after closure. The maximum Tc-99 groundwater concentration predicted from the WCF was 82 pCi/L 790 years after closure. The peak Tc-99 concentration in the OU 3-14 model is predicted to exceed MCLs briefly in 1999 and is predicted to be 10 pCi/L in 92 years. Because the predicted peak concentrations from each non-CERCLA source are much less than the MCL of 900 pCi/L and occur post-2095, and the peak predicted concentration post-2095 from CERCLA sources (10 pCi/L) is also much less than the MCL, there would be no concerns for cumulative risk, even if the maximum predicted concentrations from the non-CERCLA INTEC sources occurred at the same place and time and were summed.

Therefore, no concern exists over cumulative effects between the closed tanks, WCF, and the tank farm soil. As more INTEC facilities are deactivated, decontaminated, and decommissioned or are closed, the cumulative impacts can be assessed during each CERCLA 5-year review.

1.3.13 Feasibility Study Conceptual Design Basis

The following information was used as the basis for developing the FS:

1. Industrial use area – All OU 3-14 soil sites are within an industrial use area (see Figure 1-2) that was established in the RI/BRA. Future residential use is not considered reasonable due to the presence of permanent barriers, such as the WCF, which was grouted in place under RCRA, and the tank farm tanks, which are planned to be emptied, cleaned, and grouted in place under RCRA. More detail on the designation of this area for industrial use can be found in Section 4.2.2 of the RI/BRA (DOE-NE-ID 2006).

2. Institutional controls – DOE is committed to maintaining institutional controls for at least 100 years. Because the first comprehensive RODs for an individual WAG were signed in 1995, and the original schedule in the FFA/CO (DOE-ID 1991) was for all RODs to be submitted by 2001, all subsequent documents have assumed that active institutional controls (e.g., fences and guards) can be maintained through the year 2095. Passive institutional controls, e.g., deed restrictions and permanent markers, are assumed to be effective for the duration of risk. However, DOE will not rely on institutional controls alone as the sole remedy to mitigate risks that will remain above allowable levels after 2095. An active remedy that includes more than institutional controls, such as pump and treat, can continue beyond 2095 and have active institutional controls as a component of the remedy. A remedy that relies solely on institutional controls cannot assume there will be active institutional controls after 2095. Institutional controls are assumed to be completely effective during the period of active institutional controls. If risks

will decay to acceptable levels prior to the end of the active institutional control period in 2095, no other remedial actions, which could increase the risk to workers, will be evaluated.

3. Risk assessment – There are two human health risk assessment scenarios under the CERCLA program at the INL Site that are appropriate for OU 3-14:

   a. The industrial use scenario evaluates risk to current and future workers from exposure to the top 4 ft of soil.

   b. Workers and the public are assumed to be provided safe drinking water until 2095. After 2095, it is assumed that hypothetical future residents living outside the industrial use area can drill wells and be exposed to contaminated water.

4. Remedial action alternatives –

   a. Under the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), a No Action alternative is required to be evaluated. However, as discussed further in Section 3, the true No Action alternative is not implementable as per DOE Order 5400.5 (Radiation Protection of the Public and the Environment), Chapter II, (1)(a,b) and is not evaluated. A limited action alternative (Institutional Controls) is evaluated and meets the intent of the No Action alternative.

   b. Sites CPP-15 and CPP-58 pose an unacceptable risk from direct exposure to Cs-137 to the current worker (assuming a worker would work 40 hours a day, 50 weeks per year for 25 years on top of one of these sites). The Cs-137 will decay to acceptable levels prior to the end of the institutional control period in 2095; therefore, the sites do not pose an unacceptable risk to future workers. Institutional control until the concentrations decay to acceptable levels is the only remedy that was evaluated in the FS for these two sites.

   c. Due to the interrelationship between contaminated soil and groundwater in OU 3-14 and infiltration controls and perched water in OU 3-13, some alternatives are developed that include combined OU 3-14 remedial alternatives with OU 3-13 infiltration controls to reduce perched water.

   d. The GRAs developed for the soil inside the tank farm boundary include institutional controls and containment to protect workers from direct exposure to Cs-137 contaminated surface soil. Although the RI/BRA model predicted that the residual risk from the strontium-90 currently remaining in the alluvium does not pose an unacceptable risk to the SRPA, GRAs of in situ and ex situ treatment, removal, and disposal were developed for Site CPP-31 soil at depth in order to provide the decision-makers with a range of alternatives. The strontium-90 that migrated out of the alluvium over the last 30 years and is currently in the perched water and interbeds poses an unacceptable risk, and the strontium-90 activity that remains in the alluvium poses an insignificant increase in risk.

   e. Existing liquid transfer lines in the tank farm will remain active through the projected life of INTEC (assumed to be 2035). Therefore, relatively thick multilayer engineered final covers are less technically feasible than relatively thin simple maintenance covers because occasional inspection and repair of the lines and continued use of valve boxes will be required.

f. Remedial alternatives have been developed for the SRPA to serve as the basis for selecting a final remedy for the SRPA within and outside the INTEC security fence.

g. The level of detail required for the descriptions of specific technologies and alternatives is established somewhat qualitatively with the overall goal of (1) producing a defensible FS that can adequately compare alternatives and produce a cost estimate within the -30 to +50% range cited in CERCLA guidance and (2) ultimately allowing for selection of a remedial alternative.

5. Disposal sites – The Idaho CERCLA Disposal Facility (ICDF) will be available for disposal up until 2013, which is the planned date for closure of ICDF. It is assumed that all excavated soils will meet the ICDF Waste Acceptance Criteria (WAC) and that the average concentration in the waste volume will be <10 nCi/g transuranic constituents (beyond uranium on the periodic table, such as isotopes of plutonium, neptunium, and americium). This is based on an analysis of sampling data (the average concentration of transuranic constituents in the CPP-31 borehole was 2 nCi/g). For disposal post-2013, it is assumed that disposal is available off-Site, with the WAC no more rigorous than the WAC for the ICDF.

6. Disposal of generated waste – Soil or debris generated as a result of OU 3-14 remediation activities and transferred for disposal at ICDF will not be subject to Hazardous Waste Determination Requirements (IDAPA 58.01.05.006 [40 CFR 262.11]), Land Disposal Restrictions (LDRs) (IDAPA 58.01.05.011 [40 CFR 268]) as cited by IDAPA 58.01.05.011, or Alternative LDR Treatment Standards for Contaminated Soil, (IDAPA 58.01.05.011 [40 CFR 268.49]). Soil or debris generated after 2013 will need to meet these requirements for off-Site disposal. This is discussed further in Section 4.3, ARARs.

7. RCRA – RCRA Subtitle C landfill closure requirements as defined under 40 CFR 265.310 will not apply to the final OU 3-14 remedy because the tanks, piping, and sand pads are assumed to be clean-closed; and risks to human health and the environment from releases to soil or residual contaminants in tanks, piping, and sand pads by RCRA constituents were determined in the risk assessment conducted for tank closure to be acceptable.

8. DOE orders – DOE Orders 5400.5 and 435.1 are to be considered for all of the alternatives. These respective DOE orders minimize radiation exposure to workers and the public and provide direction for management of radioactive waste.

9. Emptying the tanks – The Integrated Waste Treatment Unit (IWTU) is a new treatment facility located at INTEC that will treat liquid sodium-bearing wastes currently being stored in the INTEC Tank Farm Facility. The IWTU will use steam reforming technology to convert the liquid sodium-bearing waste to a granular solid waste that will then be packaged in canisters suitable for transport and storage in an underground repository (e.g., Waste Isolation Pilot Plant in New Mexico). IWTU construction will be complete in the spring of 2009 with operations beginning in December 2009. IWTU will operate until the tank farm tanks are empty, which is planned for spring 2011. Following IWTU operations, the tanks are planned to be cleaned, grouted, and closed by December 2011.

10. Tanks, lines, and surface structures – There are four tank farm operations and closure assumptions, per current life-cycle baseline planning.

a. Tanks WM-180 through WM-186 (western tank farm) will be cleaned and grouted on or before September 30, 2012.

b. Tanks WM-187 through WM-190 (4-pack) will be cleaned and grouted on or before September 30, 2012.

c. Some active lines (both process and utility) will remain in the western tank farm after September 30, 2012. Rerouting of lines was previously evaluated (in INEEL [2004]) and will not be considered further.

d. All surface structures in the portion of the western tank farm that covers CPP-31 will be leveled approximately to grade on or before September 30, 2012. However, some below- or at-surface structures, such as valve boxes and electrical duct banks, may be at approximately 8 in. above grade once filled with grout.

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40 CFR 268.49, 2005, “Alternative LDR treatment standards for contaminated soil,” Code of Federal *Regulations*, Office of the Federal Register, August 2005.

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2. DEVELOPMENT OF REMEDIAL ACTION OBJECTIVES

This section includes a discussion of contaminants of concern (COCs), preliminary remedial action objectives, and preliminary remediation goals (PRGs).

2.1 Introduction

Remedial action objectives (RAOs) for the Operable Unit (OU) 3-14 Feasibility Study (FS) are developed in this section. Inputs to developing the RAOs include the conceptual site model, site groupings, the results of the baseline risk assessment (BRA), and significant chemical-specific applicable or relevant and appropriate requirements (ARARs). The resulting RAOs are word statements that specify the media, COCs, potential exposure routes, and PRGs to protect human health and the environment and ensure that the site complies with ARARs.

RAOs are used throughout the FS process, first to aid in identifying technologies and, later, as a basis for evaluating their effectiveness. The objectives for protection of human health and the environment can be achieved by reducing or eliminating exposure routes as well as by reducing contaminant concentrations. In the OU 3-14 BRA evaluation of exposure routes, three potential human receptor populations based on current and future land use scenarios were considered. The human receptors are (1) current site workers, (2) hypothetical future site workers, and (3) hypothetical future residents that would be located in areas outside the industrial use area (see Figure 1-2). The BRA evaluated potential exposure routes primarily from contaminated soil for the workers and from contaminated groundwater for future residents as shown on the conceptual site model (see Figure 1-3).

The soil pathway evaluated in the BRA included exposure routes for current and future (beyond the year 2095) workers. The conceptual site model depicts the exposure routes for each scenario, which are direct exposure; soil ingestion; dermal contact; and inhalation. However, the BRA concluded that there are no total cancer risks above 1E-06 and no hazard quotients in excess of 1 for any of the human receptor populations for the inhalation exposure route. In addition, the BRA concluded that the soil ingestion and dermal contact exposure routes were also insignificant contributors to risk. Therefore, the only soil exposure route that is evaluated further in this FS is direct exposure to gamma-emitting radionuclides.

The groundwater pathway evaluation in the BRA included exposure routes for the hypothetical future resident. The conceptual site model depicts the exposure routes for this scenario, which are ingestion, inhalation, and dermal contact. The BRA concluded that the inhalation and dermal contact exposure routes were insignificant contributors to risk. The water supply at INTEC is institutionally controlled, and workers are currently provided water from production wells that are upgradient of INTEC. The BRA evaluated ingestion of contaminated water by a hypothetical future resident living outside of the industrial use area rather than a future worker. This is because a resident is assumed to have a higher rate of exposure to drinking water than a worker, and the residential exposure route is more protective. Therefore, the only groundwater exposure route that is evaluated further in this FS is ingestion of contaminated groundwater by a hypothetical future resident.

The ecological risk assessment performed in the OU 3-13 Remedial Investigation (RI)/FS was updated in the OU 3-14 RI/BRA. The ecological risk assessment follows the approach presented in the *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL* (VanHorn, Hampton, and Morris 1995) and uses the 0 to 10-ft depth for evaluation. The results of this assessment found that maximum contaminant concentrations at both CPP-15 and CPP-58 are at acceptable levels for ecological receptors. However, at sites located inside the tank farm boundary, internal exposure to Cs-137 and Sr-90 could equal or exceed hazard indexes (HIs) of 10. Therefore, care should be taken to ensure that cleanup values used within the tank farm boundary also include consideration of ecological receptors. However, these sites were assessed as if they had freely available habitat for ecological receptors, and this is not the case. These sites are within the tank farm boundary where weed and other controls are used to discourage natural habitat and the sites are covered by asphalt, structures, or gravel. Therefore, although ecological receptors should be considered, they should not be the drivers for any cleanup levels for sites located within the tank farm boundary.

The process of developing specific RAOs and PRGs for OU 3-14 is presented in three steps:

1. Identify COCs with respect to media exposure pathways

2. Develop RAOs for the soil and groundwater pathway

3. Develop specific PRGs for OU 3-14 COCs based on the RAOs and chemical-specific ARARs.

2.2 Contaminants of Concern

For the soil pathway, the OU 3-14 RI/BRA identified that Cs-137 was the only COC for humans. The risks from direct exposure to Cs-137 contaminated surface soils were much greater than 1 in 10,000 of developing an excess cancer in a lifetime for both the current and future worker inside the tank farm boundary and for a current worker at Sites CPP-15 and CPP-58, which are located outside the tank farm boundary. The excess cancer risks from all other carcinogenic contaminants combined were less than 1 in 10,000. For ecological receptors within the tank farm boundary, Cs-137 and Sr-90 are the only COCs.

The groundwater beneath INTEC currently exceeds maximum contaminant levels (MCLs) for Sr-90, Tc-99, I-129, and nitrate in one or more wells. In addition, the OU 3-14 RI/BRA model predicted that Sr-90 would continue to exceed MCLs beyond the year 2095 because of leaching of Sr-90 from the perched water and vadose zone, but the concentrations of the other contaminants would meet MCLs by the year 2095. The modeling predicts that the combined hazard index (HI) from all noncarcinogens will be 0.06 in the year 2095.

2.3 Remedial Action Objectives

RAOs that affect the Snake River Plain Aquifer (SRPA) are defined as follows:

I. Prior to 2095, prevent current workers and the general public from ingesting SRPA groundwater contaminated by INTEC releases that exceeds applicable State of Idaho groundwater quality standards (currently identified as 8 pCi/L for Sr-90, 900 pCi/L for Tc-99, 1 pCi/L for I-129, and 10 mg/L for nitrate measured as nitrogen); a cumulative excess cancer risk from all carcinogens of 1 in 10,000; or an HI of 1.

II. In 2095 and beyond, ensure that concentrations of all contaminants in SRPA groundwater contaminated by INTEC releases do not exceed State of Idaho groundwater quality standards, a cumulative excess cancer risk from all carcinogens of 1 in 10,000, or an HI of 1.

Total excess cancer risk and HI will be determined by summing contaminants that are predicted to be in the SRPA at the same place and time. The results of the BRA model predicted that Sr-90 would exceed the MCL of 8 pCi/L in 2095 and beyond. No noncarcinogens have been identified that would exceed an MCL, and the total HI is currently below 1 and predicted to remain below 1.

RAO II can potentially be met through combinations of actions (a) on the alluvium and/or the SRPA under OU 3-14 and (b) on the vadose zone below the alluvium (perched water, interbeds, and/or basalt) and/or recharge (controls on infiltration and anthropogenic water) under OU 3-13 Group 4.

RAOs for the OU 3-14 soils are defined as follows:

III. Prevent external exposure to current and future workers inside the tank farm boundary to Cs-137 contaminated alluvium in the top 4 ft of soil, including biotic transport, that would exceed an excess cancer risk of 1 in 10,000.

IV. Prevent external exposure to current workers at Sites CPP-15 and CPP-58 to Cs-137 contaminated alluvium in the top 4 ft of soil that would exceed an excess cancer risk of 1 in 10,000.

V. Prevent internal exposure to Cs-137 and Sr-90 inside the tank farm boundary that would exceed an ecological hazard quotient of 10 for an individual contaminant and a total HI of 10.

The RAOs for soil are focused on external exposure because exposure from gamma-emitting radionuclides represents the predominant risk. The risk and hazard quotient for other exposure routes, such as soil ingestion, are well below the risk threshold of 1×10^{-4} or the hazard quotient of 1 and are extremely small (0.0002% or less of the total) relative to impacts from external exposure. RAO III also addresses the potential for biotic transport of contamination as a possible pathway. To ensure the protection of workers, it is necessary to inhibit transport of COCs to the surface by plants and animals. Intrusion by deep-rooted plants and burrowing mammals and insects (ants) into contaminated soil can create a pathway for movement of contamination to the surface.

2.4 Preliminary Remediation Goals

To meet the RAOs, remediation goals are established. These goals generally are quantitative cleanup levels that would meet ARARs and risk-based levels and would be protective of human health and the environment. The remediation goals are based on the results of the BRA and evaluation of expected exposures and risks for selected alternatives. The remediation goals will be used to assess the effectiveness of the selected remedial alternatives in meeting the RAOs.

A 1-in-10,000 incremental lifetime cancer risk is the primary basis for determining PRGs for soil at the OU 3-14 sites. The higher end of the carcinogenic risk range has been selected because the carcinogenic risk at INTEC from natural background radiation due to surface elevation and background soil radiological contamination is estimated at 1 in 10,000 (EPA 1994, NEA 1997, and UNEP 1985).

The PRGs for OU 3-14 soils for Cs-137 were developed from EPA PRGs (EPA 2006). The EPA PRGs are back-calculated, current soil concentrations that correspond to a risk of 1 in 1,000,000. They are calculated using standard EPA exposure route equations and EPA cancer slope factors.

PRGs are provided for outdoor worker soil. The outdoor worker is assumed to be a long-term receptor exposed during the workday who is a full-time employee working on-Site and who spends most of the workday conducting maintenance activities outdoors. The outdoor worker is expected to have an elevated soil ingestion rate (100 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust.

For future outdoor workers, the EPA PRG for outdoor worker soil was initially selected. Because the EPA PRGs are calculated for a 1-in-1,000,000 target risk criteria, they were multiplied by 100 to obtain the PRGs for the 1- in-10,000 risk criteria set for the OU 3-14 sites (target risk is in the numerator of the PRG equation). Also, because the EPA PRGs are calculated for a current exposure scenario, they were divided by an exponential decay factor to obtain the PRG for the future (starting in 2095) worker exposure scenario established for the OU 3-14 sites. This decay factor was calculated as [$e^{-\lambda t}$], where λ = Cs-137 decay rate constant (0.023 yr^{-1}) and t = decay time between the remedial decision or cleanup date and the start of exposure scenario in 2095. For example, the Cs-137 PRG in 2004 for future outdoor worker exposures starting in 2095 is

$$11.3 \text{ pCi/g} / \text{e-}((0.023 \text{ y}^{-1})(91 \text{ y})) = 92 \text{ pCi/g}.$$

The results of these calculations are summarized in Table 2-1.

The residential PRGs were previously used for radionuclides provided in a Memorandum (Radionuclide Risk-Based Concentration Tables) from the Idaho Department of Environmental Quality (Fromm 1996). The PRG for the future resident for Cs-137 presented in this memorandum was 23 pCi/g. Although not generally presented as a remediation goal at the INL Site, the PRG for Cs-137 for the future worker presented in Fromm (1996) would be 110 pCi/g (decayed through the exposure period). Unlike the Fromm memorandum, the new EPA guidance differentiates indoor and outdoor worker scenarios (EPA 2006) to account for gamma shielding. The gamma-shielding factor affects the calculated risk based on the amount of time spent indoors because the building structure provides some shielding from direct radiation. However, it is not anticipated that buildings will be built in the future over the OU 3-14 sites; therefore, the lower PRG for outdoor workers, which does not take credit for gamma shielding provided by buildings, is appropriate. The updated future outdoor worker PRGs primarily differ from previous PRGs at the INL Site because OU 3-14 soil sites are in an industrial use area and the future residential scenario will not be used to set cleanup goals. The PRG will apply to the top 4 ft of alluvium in the industrial use area. The final remediation goals will be used to verify the effectiveness of the selected remedial action and to determine if additional remedial action is necessary prior to termination of the remedial action.

Table 2-1. Soil risk-based preliminary remediation goals for Cs-137.

	Cs-137 Soil Concentration (pCi/g)
Remedial Decision Date/ Exposure Scenario	Outdoor Worker PRG for a 1-in-10,000 risk (Industrial Use Area)
Current/Current[a]	11.3
2004/Future[b]	92
Future/Future[c]	11.3 / [$e^{-\lambda t}$]

a. Outdoor worker remediation goal for 10^{-4} target risk and current exposure scenario, calculated as the EPA PRG × 100 (EPA 2006).
b. Outdoor worker remediation goal in 2004 (date of most recent soil sampling) for future exposures beginning in 2095, calculated by dividing the current exposure PRG (11.3 pCi/g) by the exponential decay factor [$e^{-\lambda t}$], where t = time between 2004 and the start of the future exposure scenario in 2095 (91 years).
c. Outdoor worker remediation goal at some future remedial action date, calculated by dividing the current PRG (11.3 pCi/g) by [$e^{-\lambda t}$], where t = time between the future remedial date and the start of the future exposure scenario in 2095.

Groundwater PRGs are based on meeting the MCLs in groundwater by the year 2095 and beyond and are presented in Table 2-2. The PRG for beta-gamma-emitting radionuclides (tritium, Sr-90 and daughters, I-129, and Tc-99) is restricted to a cumulative dose of 4 mrem/yr in the year 2095 and beyond. The cumulative dose is determined by contaminants that overlap in space and time. The cumulative dose from alpha-emitting radionuclides (such as Am-241, Np-237, and Pu isotopes) is much lower than the MCL of 15 pCi/L for all alpha-emitting radionuclides.

Table 2-2. Groundwater preliminary remediation goals for the year 2095 and beyond.

Contaminant of Concern [a]	PRG
Sr-90	8 pCi/L
Total (Sr-90, I-129, and Tc-99)	4 mrem/yr

a. Tc-99, I-129, Sr-90, and nitrate currently exceed MCLs in the SRPA but Tc-99 I-129, and nitrate are predicted to meet MCLs before 2095.

2.5 References

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3. TECHNOLOGY IDENTIFICATION, SCREENING, AND EVALUATION

This section consists of an introduction (Section 3.1), which describes the use of the conceptual site model (CSM) in developing actions, the waste groups, and the general response actions (GRAs). Section 3.2 identifies the remedial technologies and process options and provides a preliminary screening based on implementability. Technologies and process options that pass the preliminary screening are evaluated further in Section 3.3 based on effectiveness and relative cost. Section 3.4 presents the representative process options (RPOs) that will be used to develop the remedial alternatives that are presented in Section 4.

3.1 Introduction

This section identifies, screens, and evaluates technology types and process options that may be applicable for remediation of tank farm soil and groundwater at INTEC. The tank farm is an operational industrial facility with some elements that will remain active until at least 2035. Therefore, this section discusses both technologies that can be implemented in phases during the operational period, as well as final actions that can only be implemented after operations cease.

A primary objective of this feasibility study (FS) is to identify remedial technologies and process options that may potentially meet Operable Unit (OU) 3-14 remedial action objectives (RAOs) for contaminated soil and groundwater and then combine them into a range of remedial alternatives. The potential remedial technologies are evaluated for implementability, effectiveness, and relative cost in eliminating, reducing, or controlling risks to human health and the environment (i.e., ecological receptors). The criteria for identifying, screening, and evaluating potentially applicable technologies are provided in EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988) and in the National Contingency Plan (NCP) (40 CFR 300.430(e)(1)(I)).

CERCLA requires development and evaluation of a range of responses, including a No Action alternative, to ensure that an appropriate remedy is selected. The selected final remedy must comply with applicable or relevant and appropriate requirements (ARARs) and must protect human health and the environment. The technology screening process consists of a series of steps that include

- Identifying GRAs that may meet RAOs, either individually or in combination with other GRAs
- Identifying, screening, and evaluating remedial technology types for each GRA
- Selecting one or more RPOs for each technology type.

Following the technology screening, the RPOs are assembled into remedial alternatives (Section 4) that are evaluated further in the detailed and comparative analyses of alternatives (Sections 5 and 6, respectively).

3.1.1 Use of Conceptual Site Model and Baseline Risk Assessment

The CSM developed for the OU 3-14 Remedial Investigation/Baseline Risk Assessment (RI/BRA) report (DOE-NE-ID 2006) and results from the BRA were discussed in Section 1. Some actions on primary sources of contamination have already been taken. For example, line and valve leaks have been fixed and similar-type inferior configurations upgraded. The former injection well was plugged and abandoned and a decision made on the injection well site. Based on the CSM, actions that may meet RAOs identified in Section 2 include

- Remove secondary sources
- Remove or immobilize contaminants present in secondary sources
- Eliminate secondary release mechanisms
- Eliminate contaminant migration pathways
- Eliminate exposure routes
- Control access by receptors.

Waste and release site groupings are derived from the CSM as discussed below in Section 3.1.2. GRAs that may potentially be used to implement the actions listed above are discussed below in Section 3.1.3.

3.1.2 Waste and Release Site Groupings

Release sites are combined into waste groups with common media, contaminant sources and types, exposure pathways, and receptors to facilitate selection of remedial technologies for waste groups with similar characteristics and to reduce the repetitiveness in the technology discussions. All of the soil release sites in OU 3-14 and the contaminated backfill are by definition included in the grouping, designated as CPP-96 in the OU 3-13 ROD. Individual soil release sites at the tank farm are contaminated with similar contaminants of concern (COCs), at varying concentrations. Subgroupings are defined based on the potential for contamination of groundwater as determined in the BRA and the location inside or outside the tank farm boundary. The significance of the tank farm boundary in this context is that, inside the boundary, worker exposures were evaluated based on average concentrations measured in the top 4 ft of alluvium, due to soil excavation and redistribution of contamination, resulting in the same excess cancer risk over the entire area. Outside the boundary, worker exposures were evaluated for the individual release sites because site-specific data were available, resulting in site-specific risk estimates.

The Snake River Plain Aquifer (SRPA) grouping is based on the determination in the OU 3-13 Record of Decision (ROD) (DOE-ID 1999) that OU 3-14 would define a final remedy for the SRPA contaminated by INTEC releases, as described in Section 1.2 of DOE-NE-ID (2006). Groupings and subgroupings defined for this OU 3-14 FS therefore include

1. CPP-96

    a. Tank farm soil inside the tank farm boundary

        (1) Soil contamination inside the tank farm boundary resulting from releases at multiple sites and subsequent redistribution of contaminated soil by excavation and/or reuse as backfill, not producing significant groundwater risk, but resulting in Cs-137 direct exposure risks to current and future workers that exceed an excess cancer risk of 1E-04.

        (2) Individual release sites that contain relatively significant residual Sr-90 in the alluvium: CPP-31.

b. Tank farm soil outside the tank farm boundary not producing significant risks to groundwater or to future workers but resulting in Cs-137 direct exposure risks to current workers that exceed an excess cancer risk of 1E-04: CPP-15 and CPP-58.

2. The area of the SRPA contaminated by INTEC releases.

3.1.3 General Response Actions

GRAs are broad categories of remedial measures that produce similar results when implemented. The GRAs evaluated for OU 3-14 include institutional controls (ICs), monitoring, containment, in situ treatment, removal, ex situ treatment, and disposal. The identified GRAs may be implemented individually or in combination to meet the RAOs. The GRAs are discussed for each grouping and subgrouping identified in Section 3.1.2.

Formulation of a No Action alternative is required by the NCP (40 CFR 300.430(e)(6)). The No Action alternative serves as a baseline for evaluating other remedial action alternatives and is generally retained throughout the FS process. No action implies that no remediation will be implemented to alter the existing site conditions. As defined in CERCLA guidance (EPA 1988), no action may include environmental monitoring; however, actions taken to reduce exposure, such as site fencing or deed restrictions, are not included as a component of a No Action alternative.

DOE Order 435.1 stipulates at least 100 years of IC after closure at sites where wastes remain in place. The INTEC is projected to continue operations through 2035 and is proposed to remain a restricted, industrial-use area. ICs are in place in accordance with the *INEEL Sitewide Institutional Controls Plan* (DOE-ID 2004a). These ICs will remain in place until at least 2095 or while hazards exist that preclude releasing the area for unrestricted use. ICs at the INL Site are discussed in Section 3.2.2.1. Based on requirements under DOE Order 435.1, a true no action GRA cannot be developed or evaluated in this FS. A limited-action alternative implementing ICs will be used as the baseline for comparison to other GRAs and remedial alternatives in this FS.

3.1.3.1 Tank Farm Soil GRAs. Seven GRAs that may potentially satisfy the RAOs for tank farm soil are discussed below.

3.1.3.1.1 Institutional Controls—ICs for soil and groundwater are discussed in Section 3.2.2.1. The volume, mobility, and toxicity of the contaminants are not reduced other than through natural attenuation processes. Fate and transport of OU 3-14 COCs, including sorption to soil and radioactive decay, are discussed in Section 8 of the OU 3-14 RI/BRA (DOE-NE-ID 2006).

3.1.3.1.2 Monitoring—Monitoring alone would not reduce volume, mobility, or toxicity of COCs but could be used to determine extent of contamination above preliminary remediation goals (PRGs), as part of a removal, containment, or in situ treatment remedy or to measure progress of a remedy toward PRGs. Either field (in situ) or fixed lab radiochemical analytical techniques or both could be used to determine soil concentrations of COCs.

3.1.3.1.3 Containment—Containment isolates contaminated media from release mechanisms, transport pathways, and exposure routes using surface and/or subsurface barriers, thereby reducing or eliminating exposures to receptors. Containment alone does not reduce the volume or toxicity of the contaminants.

3.1.3.1.4 In Situ Treatment—In situ treatment reduces the toxicity, mobility, or volume of contaminants or contaminated media using physicochemical or biological technologies. Contaminant sources may be reduced or eliminated, and contaminant migration pathways and exposure routes may be eliminated. The contaminated soil is treated in place, without excavation.

3.1.3.1.5 Removal—Removal technologies reduce or eliminate contaminant sources using conventional or remote excavation and handling of contaminated soil. Removed soil is subsequently treated, stored, or disposed of.

3.1.3.1.6 Ex Situ Treatment—Based on sampling results to date, ex situ treatment of removed tank farm soil prior to disposal is not required to meet the Idaho CERCLA Disposal Facility (ICDF) Waste Acceptance Criteria (WAC). The ICDF is the only soil disposal option considered for reasons discussed below. Therefore, ex situ treatment of tank farm soil is not considered further in this FS.

3.1.3.1.7 Disposal—Disposal involves placement of excavated material in an engineered permanent waste management facility that serves to restrict contaminant mobility and mitigate exposure routes. The disposal options considered in this FS are ICDF until the estimated closure date in 2013 and then off-Site or on-Site disposal after 2013 because

1. No transuranic (TRU) waste will be generated, based upon sampling results to date indicating that total TRU will be less than 100 nCi/g upon loading into transport containers. Shipment to the Waste Isolation Pilot Plant (WIPP) will therefore not be required.

2. Wastes will meet the ICDF WAC upon loading into transport containers, based upon sampling results to date.

3. ICDF is within the Waste Area Group (WAG) 3 CERCLA area of contamination (AOC), which minimizes disposal requirements.

4. ICDF was designated in the OU 3-13 ROD (DOE-ID 1999) for disposal of CERCLA waste that is generated within the WAG 3 AOC and that meets the ICDF WAC.

The ICDF may not be available after the planned closure date of 2013. An equivalent on-Site or off-Site disposal facility could be selected if remediation continued after ICDF closed. For cost-estimating purposes, ICDF disposal costs were used before and after 2013 because it is unknown what disposal options will be available in the future.

3.1.3.2 Groundwater GRAs. Seven GRAs that may potentially satisfy RAOs identified for groundwater are discussed below.

3.1.3.2.1 Institutional Controls—ICs for OU 3-14 groundwater are discussed in Section 3.2.2.1. The volume, mobility, and toxicity of the contaminants would not be reduced other than through natural attenuation and radioactive decay processes. The fate and transport of OU 3-14 COCs are discussed in Section 8 (Summary), Appendix A (modeling details for all COCs except Sr-90, and Appendix J (modeling details for Sr-90) of DOE-NE-ID (2006).

3.1.3.2.2 Monitoring—Monitoring alone would not reduce volume, mobility, or toxicity of COCs but could be used to determine extent of contamination above PRGs, as part of a removal, containment, or in situ treatment option, or to measure progress of a remedy toward PRGs. Either field (in situ) or fixed lab radiochemical analytical techniques or both could be used to determine groundwater concentrations of COCs.

Monitoring of the perched water and SRPA contaminated by INTEC releases is currently implemented under the OU 3-13 ROD for Groups 4 and 5, respectively. The status of the Group 4 remedy is discussed in Section 1.3.6 of this FS. OU 3-13 Group 5 monitoring as well as other options are discussed below.

3.1.3.2.3 Containment—Groundwater containment isolates contaminated groundwater using physical barriers or hydraulic controls to control groundwater movement and limit contaminant migration. Institutional or engineering controls may be needed within the containment area to ensure potential exposure routes are cut off.

Containment of perched water under INTEC via recharge controls was implemented under the OU 3-13 ROD (DOE-ID 1999) for Group 4. Remedy components implemented to date include monitoring, removing the existing percolation ponds from service, partially discontinuing lawn irrigation at the INTEC, and removing the existing Sewage Treatment Plant (STP) lagoons and infiltration galleries. Additional controls may include lining the Big Lost River, curtailing steam condensate discharges to the subsurface, and curtailing additional lawn irrigation. The status of the Group 4 remedy is discussed in Section 1.3.6 of this FS.

3.1.3.2.4 In Situ Treatment—In situ treatment technologies include application of physical, physicochemical, thermal, or biological processes to reduce the toxicity, mobility, or volume of the contamination. Little or no groundwater is removed.

3.1.3.2.5 Removal—Removal technologies collect and transfer contaminated groundwater to treatment, storage, or disposal facilities using extraction wells. Removal may be used to eliminate or control groundwater contaminant sources or as part of a containment remedy.

3.1.3.2.6 Ex Situ Treatment—Ex situ treatment technologies include application of physical, chemical, biological, or thermal treatment methods to remove contaminants from extracted groundwater or to convert them to less toxic or less mobile forms.

3.1.3.2.7 Disposal—Disposal of extracted groundwater includes transport and discharge of untreated or treated groundwater to approved facilities and/or receiving waters.

3.2 Remedial Technology Identification and Preliminary Screening

3.2.1 Introduction

This section describes identification and preliminary screening of potentially effective remedial technologies for each waste group's GRAs. Technologies that might potentially meet RAOs for OU 3-14 waste groupings and COCs were identified using information available from EPA, DOE, and other sources referenced in Section 3.5, as well as through discussions with scientists, engineers, and vendors working in specific technology focus areas.

The preliminary screening of the identified technologies emphasizes evaluation of the implementability of each technology for the waste groups identified at OU 3-14. Effectiveness is a secondary consideration at this stage of screening; however, technologies that are obviously not effective in meeting RAOs for the specific release site groupings discussed previously or that might potentially increase mobility of the COCs or result in additional migration or exposure pathways were screened out.

Technology and process options judged to be potentially implementable were retained and subsequently evaluated for effectiveness and relative cost in Section 3.3. Site-specific information, including site description and contaminant characterization, was used to eliminate technologies or process options that would not apply or could not be effectively implemented. The preliminary screening process reduces the number of possible process options for a given remedial technology type to a more manageable set of options that are considered potentially applicable for contaminated soil and groundwater at OU 3-14.

Innovative technologies not developed beyond conceptual or laboratory scale were retained for further evaluation if adequate information was available to determine potential effectiveness and implementability. Lacking pilot-scale or commercial vendor information, a potential approach for implementation was described if possible. If a potential approach for implementation could not be determined, the technology was not screened out; however, the technology was not selected as an RPO for development into an alternative without this information. If no technology that may meet RAOs is identified for a specific waste grouping or if decision-makers determine that it is merited, an innovative technology from the retained list may be selected for treatability studies or scale-up in the ROD or during remedial design (RD).

The INTEC tank farm area is an active industrial facility, components of which are projected to remain in service through at least 2035. The projected tank farm operations and closure schedule as it pertains to implementation of the OU 3-14 final remedy is discussed under "FS Assumptions" in Section 1 based on current planning. The following discussion of technical implementability considers the current planning schedule of tank farm operations and closure and projects a date after which a technology could potentially be implemented.

Technologies already implemented for OU 3-14, including surface water controls implemented under the Tank Farm Interim Action (TFIA) and ICs, are also summarized in this section, and references are provided for more detailed information.

3.2.2 Identification and Preliminary Screening of Remedial Technologies and Process Options for Tank Farm Soil

Table 3-1 summarizes the initial identification and screening of remedial technologies for tank farm soil. Each of the technology process options is discussed in detail below.

3.2.2.1 Institutional Controls. ICs may meet RAOs by restricting access of receptors to contaminated soil and groundwater or by eliminating exposure routes. The methodologies and overall procedures for implementing, maintaining, and evaluating the effectiveness of ICs for the CERCLA sites at the INL Site are summarized in Table 3-1 and discussed in the following sections. ICs are currently in place and functioning at WAG 3, in accordance with the OU 3-13 ROD and as described in the *INEEL Sitewide Institutional Controls Plan* (DOE-ID 2004a). Future OU 3-14 remedial actions will include ICs consistent with the current Idaho Cleanup Project (ICP) policies and procedures.

3.2.2.1.1 Administrative Controls—

3.2.2.1.1.1 INL Comprehensive Facilities and Land Use Plan—The Comprehensive Facility and Land Use Plan (CFLUP) serves as a comprehensive listing of all areas or locations on the INL Site that have ICs for protection of human health or the environment. The information includes, at a minimum, the location of the area, the objectives of the restriction or control, the timeframe for which the restrictions apply, and the tools and procedures that will be applied to implement the restrictions or controls. Annually, the information in the CFLUP is reviewed to assure it is current, effective, and sufficient for each site. The CERCLA module of the CFLUP is revised annually as needed. The CFLUP also tracks or includes by reference any permitting changes, renovation work on structures, well placement and drilling, construction, or other activities that could occur on CERCLA sites at the INL Site with ICs. The CERCLA module of the CFLUP is available at http://cflup.inel.gov (INEEL 2003). Those portions of the CFLUP that contain specific information considered sensitive for security reasons are currently available for official use only by DOE or its subcontractors at the INL Site.

Table 3-1. Preliminary screening of technologies and process options for tank farm soil. Technologies shown with shading are eliminated based on effectiveness and implementability.

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
Institutional controls	Administrative controls	Comprehensive Facility Land Use Plan (CFLUP)	Tracks and reports activities that could occur on INL Site CERCLA sites with ICs.	Available	Present	NA	Implementable.
		Public notices	Notify stakeholders of changes in ICs.	Available	Present	NA	Implementable.
		DOE directives	Legally binding on DOE and contractors; can include well drilling restrictions or easements for monitoring, restrictive covenants, or land withdrawal documentation.	Available	Present	NA	Implementable.
		DOE environmental checklists (ECs)	DOE requires an EC be completed for all environmental projects.	Available	Present	NA	Implementable.
		Work controls	Includes specific regulatory requirements for work activities, environmental management, radiological controls, safety and industrial hygiene, and training requirements.	Available	Present	NA	Implementable.
		Notice of soil disturbance (NSD)	Required for planned disturbance, excavation, and management of soil.	Available	Present	NA	Implementable.
	Access restrictions	Visible restrictions	Barriers, permanent markers, or warning signs.	Available	Present	Inspections	Implementable.
		Access controls	INL Site access controls under the authority given in 42 USC 2278a as implemented by 10 CFR 860, "Trespassing on Department of Energy Property." Security forces and other administrative controls.	Available	Present	Inspections	Implementable.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
	Property transfer controls	Deed or regulatory restrictions	Statutes require that DOE indicate in property transfer deeds the presence of contamination and any restrictions on use of the property due to such contamination.	Available	Present	NA	Implementable.
Monitoring	Soil monitoring	Soil sampling and radiochemical analysis	Sampling of contaminated soil and radiochemical analysis to determine the concentration of COCs.	Available	Present	Surface soil sampling	Implementable.
		In situ gamma monitoring	Field gamma detectors to determine surface exposures	Available	Present	Field gamma detectors	Implementable.
Containment	Capping system	RCRA Subtitle C cap	A layered cap consisting of a compacted clay or geocomposite layer barrier and flexible membrane liner (FML) overlain by a lateral drainage layer and a vegetated soil layer.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Inspections for cover integrity	Implementable. Effective for providing clean soil buffer over contaminated soil.
		Evapotranspiration cap	"Water balance" cover that consists primarily of a vegetated soil layer and may include a capillary /biobarrier.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Inspections for cover integrity	Implementable. Effective for providing clean soil buffer over contaminated soil.
		Rock armor cap	SL-1-type cap consisting primarily of thick layer of large rock for intruder barrier.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Inspections for cover integrity	Likely to increase infiltration of precipitation.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
		Hanford barrier	An intrusion and infiltration barrier designed for an effective life of at least 1,000 years. Cap consists of an evapotranspiration component, capillary break, and asphalt barrier. Designed to isolate high-activity low-level, greater-than-class C (GTCC), mixed, and TRU wastes.	Available	Western tank farm: 2012 All of CPP-96: 2035	Inspections for cover integrity	Implementable. Effective for providing clean soil buffer over contaminated soil. Little or no maintenance after vegetation is established.
		Concrete-based cap	A single-layered capping system composed of a reinforced concrete slab placed over a prepared subgrade above the contaminated material.	Commercially available	Present	Inspections for cover integrity	Potentially implementable. Requires maintenance.
		Conventional asphalt cap	A single-layered cap composed of asphalt pavement placed over a prepared subgrade above the contaminated material.	Commercially available	Present	Inspections for cover integrity	Partially implemented under TFIA. Requires maintenance.
		MatCon asphalt	A single-layered cap composed of MatCon asphalt pavement placed over a prepared subgrade above the contaminated material.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Inspections for cover integrity	Implementable. Requires maintenance.
		Flexible membrane	Single layer of polymeric plastic.	Commercially available	Currently implemented	Inspections for cover integrity	Implementable; however, durability low without overlying protective soil layers. Not effective for reducing Cs-137 exposures.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
	Subsurface barriers	Horizontal or vertical barriers to contaminant migration	Freeze walls. Jet grouting. Permeation grouting. Hydrofracturing. Slurry walls. Sheet pilings. Permeable reactive walls.	Commercially available	Not determined	Various	Not effective, not implementable or implementability uncertain.
	Surface water management	Maintain/expand TFIA	Expand and maintain drainage controls to minimize surface water infiltration implemented under TFIA.	Available	Present	Neutron probe and/or other soil moisture monitoring to determine effectiveness	Potentially implementable. Not effective in reducing Cs-137 exposures.
In situ treatment	Biological	Phytoremediation	Use of vegetation grown on contaminated surface soil to assimilate radionuclides, including Cs-137, from the rhizosphere.	Commercially available	2035	Soil and vegetation sampling and radiochemical analysis	Effectiveness uncertain. Would require supplemental water, which may mobilize Sr-90.
		Ureolytically driven coprecipitation in calcite	Add organic carbon and urea amendments. Urea hydrolysis produces carbonate and elevated pH. If system is already saturated or close to saturated with respect to calcite, calcium carbonate will precipitate. Sr is sequestered by encapsulation or coprecipitation.	Conceptual Laboratory and field testing underway at INL Site	2012 if principle proven and development initiated immediately	Field samples that show evidence for Sr coprecipitation in calcite Reduced Sr concentrations downstream of Sr contamination Potential changes in permeability	Not yet tested for application in unsaturated systems. Laboratory and field testing underway at INL Site.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
		Microbial degradation of gas-phase phosphate and phosphate mineral precipitation	Volatile organic phosphate, such as tri-ethyl phosphate, is pumped into a contaminated region along with gas-phase nutrients. Microbial activity degrades organic phosphate and releases PO_4^{3-}. Phosphate minerals form and immobilize metal contaminants.	Conceptual	2012 if principle proven and development initiated immediately	Evidence for phosphate delivery where Sr contamination exists Evidence for phosphate precipitates and Sr immobilization Changes in permeability	May be easier to control gaseous additions to unsaturated zone than aqueous additions, but microbial processes at INTEC unknown. Significant development needed.
	Physicochemical	Liquid atomized apatite injection	An aerosol with particulate apatite is injected into the subsurface to distribute apatite through saturated or unsaturated porous and fractured media. The injection method has some similarities to jet grouting. Contaminants are intercepted and removed through the formation of insoluble metal phosphate minerals.	Field demonstration of particulate aerosol injection conducted by ARS Technologies (ARS Technologies 2006)	2012 (Testing would be needed for applicability to the INTEC conditions.)	Field samples showing evidence for Sr precipitation as a phosphate Evidence for phosphate distribution where Sr contamination exists or in the path of mobile Sr Reduced Sr concentrations downstream of phosphate barrier	Requires distribution in a horizontal layer in order to intercept vertically infiltrating water. Dense drilling pattern may be required to create horizontal barrier. Requires knowing gas flow paths in alluvium relative to location of contaminants. Potentially applicable.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
		Addition of aqueous phosphate amendment	Aqueous phosphate addition. Add aqueous phosphate to subsurface, often together with dissolved calcium, and/or add phosphate to surface and let percolation carry it downwards into contaminated region. Nucleate apatite throughout entire contaminated region, and immobilize Sr^{2+} within phosphate minerals.	Conceptual	2012 if principle proven and development initiated immediately	Evidence for phosphate delivery where Sr contamination exists. Evidence for phosphate precipitates and Sr precipitation. Monitor changes in permeability	Effectiveness and implementability not demonstrated.
		Aqueous carbonate/OH- addition	Add soluble carbonate (CO_3) to elevate pH and drive carbonate mineral precipitation and sequestration of Sr within or under newly precipitated minerals.	Conceptual	2012 if principle proven and development initiated immediately	Field samples showing Sr incorporation into or under new or re-formed mineral phases. Monitor changes in permeability	Effectiveness and implementability not demonstrated.
		Carbon dioxide gas injections and coprecipitation of metal carbonates	CO_2 gas injected to lower pH and dissolve carbonate and other mineral phases. Air injection to remove CO_2 raises pH and induces reprecipitation of minerals. Sr is immobilized as a precipitate or is encapsulated in precipitates.	Conceptual	2012 if principle proven and development initiated immediately	Field samples showing Sr incorporation in new or re-formed mineral phases. Monitor changes in permeability	May be easier to control gaseous additions to unsaturated zone than aqueous additions, and chemistry is well understood. Rechargeable. *Potentially applicable.*

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
		Reduction and precipitation of metals using hydrogen sulfide gas	In situ redox manipulation via gas addition. Add a gas-phase reductant (e.g., H_2S) to reduce contaminant metals and precipitate them as immobile mineral phases.	Conceptual	NA	NA	Not applicable to Sr. Sr is not sensitive to these reducing conditions.
		Reduction and precipitation of metals using dithionite	Dithoinite solution used to either precipitate redox-sensitive metals or reduce iron in native minerals that then reduce contaminant metals.	Tested at Hanford	NA	NA	Not effective for Sr. Sr is not sensitive to these reducing conditions, and uptake in reduced iron minerals is likely to be limited. Cannot maintain reducing conditions.
		Soil vapor extraction	Remove water vapor passively or actively in or below contaminated zones to create "dry barrier" or to minimize unsaturated hydraulic conductivity and thereby minimize contaminant mass flux rates.	Commercially available	Present	Neutron probe or other soil moisture monitoring	Potentially implementable. Mature, commercially available soil remediation technology.
		Solidification/ stabilization	Mix reagents with contaminated soil in situ to encapsulate contaminants.	Commercially available	2012	Soil sampling and radiochemical analysis	Low implementability due to subsurface infrastructure. Would not reduce Cs-137 direct exposure risks.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
		Soil flushing	Inject water and reagents into soil to solubilize COCs, which are then removed through extraction wells. Liquid waste stream is treated to remove COCs.	Commercially available	2012	Soil sampling and radiochemical analysis	Likely not implementable. Difficult to control in heterogeneous systems. Not proven effective for Cs-137 removal. Contamination at INTEC is in highly permeable sediments that are close to basalt. Some contaminant may escape into basalt fractures. High risk.
		Electrokinetics	Insertion of anode and cathode electrodes into contaminated soil. Water and ions move toward the electrodes where they are extracted for treatment.	Field demonstrations completed	2012	Soil sampling and radiochemical analysis	Likely not implementable. Extensive treatability testing and soil testing required. Not demonstrated for Cs-137 removal. Subsurface infrastructure would interfere.
	Thermal	In situ vitrification	Immobilization of contaminants using electrically generated heat by electrodes to convert soil to a nonleachable glasslike waste form.	Commercially available	NA	NA	Likely not implementable due to the presence of subsurface utilities and structures that conduct electrical current Requires off-gas treatment and associated waste handling/ disposition. Not effective for reducing Cs-137 exposures.

Table 3-1. (continued).

General Response Action	Remedial Technology	Process Option	Description	Technology Status	Earliest Date of Implementability	Monitoring Requirements	Screening Comments
Removal	Conventional excavators	Backhoes, trackhoes	Remove low-activity contaminated soil for disposal.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Digface monitoring for gamma radiation; sampling and radiochemical analysis for Cs-137	Potentially implementable.
	Nonconventional excavators	Vacuum excavation, remote excavator	Remove high-activity contaminated soil for disposal.	Commercially available	Western tank farm: 2012 All of CPP-96: 2035	Digface monitoring for gamma radiation; sampling and radiochemical analysis for Cs-137	Potentially implementable.
Disposal	Landfilling	ICDF	Disposal in existing ICDF.	Available	Present	None	Effective and implementable.

NA = not applicable.

3.2.2.1.1.2 Public Notices—Public notice is provided as needed to stakeholders of changes in ICs. Stakeholders are individuals, groups, and organizations who believe that they may be affected by transferring or leasing of INL Site property. The stakeholders currently considered most actively interested in INL Site activities are Shoshone-Bannock Tribes, CH2M-WG Idaho/Battelle Energy Alliance employees, Coalition 21, Environmental Defense Institute, INL Citizens Advisory Board, Snake River Alliance, Keep Yellowstone Nuclear Free, and the news media. Public communication and involvement are geared to offer opportunities to all stakeholders. For land use changes and property leasing or transfer, the stakeholders and news media are contacted and provided with the appropriate information, in accordance with the Community Relations Plan (DOE-NE-ID 2004).

3.2.2.1.1.3 Department of Energy Directives—DOE directives include policies, orders, notices, manuals, and guides intended to direct, guide, inform, and instruct employees in the performance of their jobs and enable them to work effectively within the DOE and with regulatory agencies, contractors, and the public. DOE directives are legally binding on DOE and on all of its contractors by inclusion into their contract. New orders or changes must be added to List B of the contract. Future directives and guidance concerning restricting groundwater use and access are being considered for the INL Site as part of the evaluation of controls to protect human health and the environment. These may include additional well-drilling restrictions or easements for monitoring, restrictive covenants, or land withdrawal documentation that would be deemed necessary to further protect the public and the environment if land use or ownership changes.

Activities involving water wells are subject to regulatory processes, such as under CERCLA remedial investigation and remedial action monitoring, Resource Conservation and Recovery Act (RCRA) Treatment, Storage, or Disposal (TSD) Unit monitoring, the Safe Drinking Water Act, or environmental impact analysis under National Environmental Policy Act (NEPA). Potable water supply well construction procedures must adhere to the Idaho Department of Water Resources construction standards and the requirements of well permitting under Idaho Administrative Procedure Act (IDAPA) 37.03.09.

3.2.2.1.1.4 DOE Environmental Checklists—In accordance with the June 1994 Secretarial Policy on NEPA, DOE relies on the CERCLA process for review of actions to be taken under CERCLA. CERCLA activity documents incorporate NEPA values to the extent practicable and are made available to the public in accordance with the requirements of CERCLA.

The process for a proposed action and identification of potential impacts is typically initiated with an EC prepared for review and approval. Information provided in the EC includes detailed information concerning the environmental aspects and potential sources of impact, including information on the potential disturbance of a contaminated site. During EC technical review, an appropriate specialist evaluates the information. The EC review and approval process ensures that applicable environmental requirements associated with the project have been identified and that the project will comply with all requirements.

An EC is developed for proposed activities such as drilling new potable water supply wells or modifying such wells or water supply systems. Environmental evaluation requirements apply to activities conducted on behalf of DOE Idaho by the maintenance and operations contractor, subcontractors, lessees, or any government entity such as the United States Geological Survey. The EC evaluation would assess the proposed activity to identify any restrictions on disturbance of environmental media, on well drilling, or on management of waste or subsequent water-use restrictions related to aquifer contamination.

3.2.2.1.1.5 Work Control Process—All work at the INL Site is controlled through the “Integrated Work Control Process” (STD-101). The integrated work control process is the method by which the Integrated Safety Management System (ISMS), enhanced work planning, and Voluntary Protection Program (VPP) are implemented. This process details the initiation, development, and approval of the work controls for certain projects at the INL Site. The work control process identifies specific regulatory requirements for work activities, environmental management requirements, radiological control requirements, safety and industrial hygiene requirements, and training requirements associated with a specific location. ICs are part of the regulatory/environmental management requirements.

Institutional controlled CERCLA sites with potential radiological exposures require written authorizations for entry into and work within radiological areas (10 CFR 835.501(d)). Records of these authorizations are maintained, per 10 CFR 835.701(a), to help its operating entities comply with the requirements of 10 CFR 835 and DOE G 441.1-1 through 441.1-12. This series of guides is structured to help radiation protection professionals develop the documented radiation protection program required by 10 CFR 835.101 and the supporting site- and facility-specific policies, programs, and procedures necessary to ensure compliance with the related regulatory requirements. DOE STD-1098-99, “Radiological Control,” supplements DOE G 441.1-1 through 441.1-12 and serves as a secondary source of guidance for complying with 10 CFR 835.

3.2.2.1.1.6 Notification of Soil Disturbance Process—Soil disturbances at INTEC are controlled through an additional NSD, as required in the OU 3-13 ROD (DOE-ID 1999). Any soil disturbance must be pursuant to agreement by DOE, EPA, and DEQ. The NSD process is intended to ensure that the disturbance does not interfere with specific remedial actions identified in the OU 3-13 ROD and that the remedies remain operational and functional. The established soil disturbance procedure is required for planned disturbance, excavation, and management of soil within WAG 3. The procedure applies to all resources involved in actions that may cause a soil disturbance at a CERCLA site at INTEC and within WAG 3, OU 3-13, and defined AOC.

DOE Idaho is responsible for reviewing the proposed activity and subsequently completing an NSD package. Prior to any site disturbance activities, the Agencies will ensure that remedies identified in the ROD remain operational, functional, and unimpeded (DOE-ID 1999). Appendix E of DOE-ID (1999) details the soil management strategy process for soil disturbances.

3.2.2.1.2 Access Restrictions—

3.2.2.1.2.1 Visible Access Restrictions—Visible access restrictions are those ICs that restrict personnel access at a specific CERCLA site. Visible access restrictions may include barriers, permanent markers, or warning signs. Warning signs are the predominant method of access restriction at the INL Site. They identify the location of CERCLA sites to any persons who may intentionally or inadvertently enter or disturb a site. Warning signs are posted at sites when residual contamination at the site may pose a current or future risk to human health or the environment if excavated or otherwise disturbed.

A work site at the INL Site may not need to be posted with a warning sign if

- It is subject to a comprehensive ROD and it has been determined that no chemical or radiological contaminants are present at the site.
- It is subject to a comprehensive ROD and chemical and radiological contaminant(s) at the site do not pose an unacceptable risk to workers, the public, or the environment, if disturbed.

New sites that are identified at the INL Site may be posted with warning signs prior to being subject to a final ROD. These sites are tracked on an internal database and are included in the CERCLA module of the CFLUP when subject to a ROD. Signs for new sites reflect the requirements of this plan.

Warning signs provide, as a minimum, information on the principal hazard(s) at the site, the media of concern, a point-of-contact with phone number, and a warning to not disturb the area unless authorized. The potential hazard(s) information is generalized (e.g., organics, inorganics, radionuclides, polychlorinated biphenyls, asbestos, or ordnance) without identifying specific chemicals or radionuclides. The format of the signs is consistent throughout the INL Site. Guidance on signage content and placement is provided in the IC Plan (DOE-ID 2004a).

3.2.2.1.2.2 Access Control—Unauthorized access to the INL Site is controlled under the authority given in 42 USC 2278a as implemented by 10 CFR 860, "Trespassing on Department of Energy Property." The INL Site facilities require identification badges to enter. Any member of the general public who visits the INL Site must pass through visitor control, obtain a visitor pass, and be escorted by authorized personnel. DOE Idaho maintains a security force responsible for controlling access to all INL and ICP facilities. The access control procedures used by the security force can be found in

- DOE O 470.4, Safeguards and Security Program.

Sites that pose a radiological exposure risk to personnel or visitors are physically and administratively controlled so that only trained radiation workers can access the sites, as designated under 10 CFR 835, "Occupational Radiation Protection." Worker exposure is also maintained under the as-low-as-reasonably-achievable (ALARA) program. Physical controls for accessing CERCLA sites posing radiological hazards include warning signs, fences, barriers, and boundary markers. Administrative controls include radiological work permits (RWPs) and personnel training.

3.2.2.1.3 Restrictions on Leasing or Transferring Property—It is not anticipated that the land within INL Site will be leased or transferred at least through the year 2095. The Hall Amendment of the National Defense Authorization Act of 1994 (Public Law 103-160, § 3154) requires concurrence from EPA on the lease of any National Priorities List (NPL) sites during the period of DOE control. DOE will also, to the extent practicable, seek to use the standards in the EPA's "Interim Final Draft Policy Institutional Controls and Transfer of Real Property under CERCLA Section 120(h)(3)(A) (B) or (C)" (EPA 2000).

CERCLA (42 USC 9620 (h)(3)) requires that DOE indicate in property transfer deeds the presence of contamination and any restrictions on use of the property due to such contamination. DOE will notify the EPA and the DEQ as soon as DOE decides to seek a lease or other real property transaction affecting any property subject to ICs so that the EPA and the DEQ can be involved in discussions to ensure that appropriate provisions are included in the conveyance documents to maintain effective ICs. Portions of the INL Site are located on land withdrawn from public domain by Public Land Orders 318, 545, 637, and 1770. The land withdrawn under these orders accounts for approximately 89% of the current INL Site. DOE owns the balance of land that was obtained from private parties or the State of Idaho.

3.2.2.1.4 Transfer to Management by Other DOE Programs or Other Federal Agencies—The ICs put in place pursuant to CERCLA will continue without modification or interruption following transfer of any part of the INL Site to another government program or entity. All primary documents bind the federal government, not a single element of that government. Neither NEPA nor other environmental laws would require any new action in connection with such an intra-DOE transfer of responsibility.

3.2.2.1.5 Response to Failed Controls/Corrective Action—Failed controls are most likely found during the annual assessments; however, failed controls may be discovered at any time. DOE Idaho will notify the EPA and the DEQ after discovery of any major activity (e.g., unauthorized well drilling, intrusion into engineered covers, change in land use from industrial to residential) inconsistent with the specific ICs for a site or of any change in the land use or land use designation of a site addressed in the ROD and listed in the CFLUP. Minor inconsistencies (e.g., signs down or missing) will be resolved as necessary. If minor inconsistencies are identified during the annual assessment, they will be noted on the reports and resolution will be noted in the report.

If DOE believes that an emergency exists, DOE can respond to the emergency immediately before notification to the EPA and the DEQ and need not wait for any EPA or DEQ input to determine a plan of action. DOE will identify the root cause of the IC process failure, evaluate how to correct the process to avoid future problems, and implement these changes after consulting with the EPA and the DEQ.

3.2.2.1.6 Changing/Terminating Institutional Controls—ICs are required as long as land use or access restrictions are necessary to maintain protection of human health and the environment. New sites that are determined to require ICs will be included in the WAG 3 Institutional Control Plan and in the CFLUP as ROD-pending IC sites. The adequacy of the continued use of ICs for each CERCLA site will be evaluated during the annual IC assessments and the CERCLA 5-year review process. RODs specify that ICs will be deleted or terminated during the 5-year review when the parties to the Federal Facility Agreement and Consent Order agree in the deletion or termination. Because the CFLUP lists the required ICs at CERCLA sites, changes or terminations agreed to by the Agencies will be documented in the updated CFLUP, as well as in the updates to the WAG 3 Institutional Control Plan. In this way, the CFLUP supports the requirements of the Institutional Controls Plan in tracking ICs for the CERCLA sites.

3.2.2.1.7 Assessments of CFLUP IC Information—The INL Site CFLUP provides guidance on facility and land use at the INL Site through the 100-year (year 2095) scenario (INEEL 2003) and beyond. The CFLUP includes a CERCLA module with specific information about the INL CERCLA sites. The CERCLA module of the CFLUP is to include the following:

- A list of all CERCLA institutionally controlled areas with descriptions
- A list of required ICs for each CERCLA site
- The objective of the control or restriction
- The control or restriction.

3.2.2.2 Monitoring. Monitoring may be used in combination with other technologies to meet RAOs. Monitoring for tank farm soil could include initial determination of extent of contamination above PRGs, determination of soil COC concentrations during excavation, postremedial action characterization to determine compliance with cleanup goals, and long-term monitoring. Cs-137 (direct exposure) and Sr-90 (potential migration to groundwater) are the only COCs identified for OU 3-14 soil; therefore, monitoring for these radionuclides is discussed below.

3.2.2.2.1 Sampling and Analysis—Sampling and radiochemical analyses are frequently performed on the INL Site to determine soil concentrations of radionuclides, including Cs-137 and Sr-90. The *Quality Assurance Project Plan for Waste Area Groups 1, 2, 3, 4, 5, 6, 7, 10 and Deactivation, Decontamination, and Decommissioning* (DOE-ID 2004b) cites analytical methods and quantitation limits for Cs-137 and Sr-90 in soil as follows:

Radionuclide	Analytical Method	Quantitation Limit
Cs-137	Gamma spectroscopy	0.1 pCi/g
Sr-90	Gas proportional counter	0.5 pCi/g

Sampling and radiochemical analysis become more complex and costly for materials with high direct radiation exposure levels. However, administrative work controls and physical controls, including gloveboxes, can reduce exposures to allowable levels. Sampling and radiochemical analysis are effective and implementable and are retained for further consideration.

3.2.2.2.2 In Situ Gamma Monitoring—In situ gamma surveys using direct-reading instruments can be effectively used for initial site assessment and to locate the extent of surface activity to plan subsequent excavation, while gamma spectroscopy can be used to determine the extent of Cs-137 contamination above the future worker PRG of 92 pCi/g. Both types of systems are discussed below.

Historically at the INL Site, soil contamination surveys have been performed by radiological control technicians (RCTs) using hand-held sodium iodide (NaI) detectors to determine gamma radiation levels. If the RCT detected any elevated readings during the survey, a Bicron MicroRem meter was used to determine the exact radiological activity and compare it to the release limits. The RCT recorded all information into a field logbook and documented any elevated areas. These data were later transcribed onto a map and reported to the D&D organization. These types of detectors are not calibrated to specific radionuclide soil concentrations; therefore, readings cannot be converted to Bq/g or pCi/g.

More recently at the INL Site, the Global Positioning Radiometric Scanner (GPRS) system operated by the Environmental Surveillance Program (ESP) has been used for conducting routine large-area surface radiation surveys. These surveys are part of a routine surveillance program and are conducted outside the facility fence lines and within known contaminated soil areas to ensure that no migration of contaminants has occurred. The GPRS system uses a detection system, differential global positioning system (GPS), a portable computer, and a four-wheel-drive vehicle. The detection system consists of two plastic scintillators, each with an independent amplifier channel on a single-channel analyzer board and sharing a common high-voltage power source. Each detector is shielded with 1/8 in. of lead on the top, sides, and ends to allow the system to collect measurements directly below the unit. The unit records in μR/hr. The unit is not calibrated to specific radionuclide soil concentrations; therefore, readings cannot be converted to Bq/g or pCi/g.

In situ gamma spectroscopy can determine soil concentrations in Bq/g or pCi/g of specific gamma-emitting radionuclides using a portable Ge detector and detector holder, laptop PC, data analysis software, and calibrations for the likely sample geometries. A system marketed by Canberra can reliably detect Cs-137 at less than 0.1 Bq/g (less than 3 pCi/g) where fuel processing and reprocessing wastes are present, as for OU 3-14. Counting times are about 15 minutes. The results are available immediately for use to determine the need and strategy for further measurements or to guide the excavation effort. GPS can be integrated with the in situ gamma spectroscopy system to provide automatic sample location information (latitude, longitude, and elevation) to within a meter and to record this with the sample information. Various mapping software can be used to produce maps of spatial distribution of soil concentrations.

Based on the previous discussion, both sampling and radiochemical analysis and in situ gamma monitoring technologies will be retained for further consideration for tank farm soil surveillance and monitoring.

3.2.2.3 Containment. Containment technologies isolate wastes and minimize contaminant migration using surface or subsurface engineered barriers. When properly constructed and maintained, containment technologies can prevent or reduce migration of hazardous substances into the surrounding environment, eliminate or reduce direct exposure to waste, and control run-on and run-off to the site. While containment can reduce the mobility of contaminants, it does not reduce their toxicity or volume. Containment technologies, including capping, and surface water controls are discussed below.

3.2.2.3.1 Capping—Capping refers to a wide range of engineered surface barrier technologies that may potentially meet RAOs by eliminating or controlling secondary release mechanisms, eliminating contaminant migration pathways, or eliminating exposure routes.

Capping to prevent exposures to future workers (RAO III) would require a minimum of 4 ft of clean soil over the extent of tank farm soil inside the tank farm boundary. The 95% upper confidence limit (UCL) concentrations of Cs-137 in tank farm soil inside the boundary will remain above the 1E-04 excess cancer risk level of 11.3 pCi/g for about 220 years. The cap would have to provide a 4-ft-thick layer of clean soil for at least this long to remain completely effective. Capping would not be implemented solely to protect current workers, because existing administrative controls are completely effective for this purpose.

Capping to meet RAOs I and II would require reducing infiltration rates sufficiently that Sr-90 concentrations after 2095 would not exceed applicable groundwater quality standards in the SRPA. Given that RI/BRA base case modeling indicated that Sr-90 concentrations will remain above the maximum contaminant level (MCL) until 2129, the cap is assumed to have to remain effective at controlling infiltration for at least 117 years. The required areal extent of an infiltration control cap to meet RAOs I and II is discussed in Section 4.

Capping would not be implemented solely to prevent exposure of ecological receptors (RAO V) but would mitigate exposures to varying degrees depending on the type of cap used. Radionuclide detections at CPP-26 were the primary risk drivers for ecological risks for tank farm soil. The shallowest detections occurred at a depth of 3.8 to 4.7 ft below ground surface (bgs). A soil cover at least 4 ft thick, as required to meet RAO III, would result in about 8 ft of clean soil over the shallowest contamination and would reduce exposures to plants and burrowing animals to minimal levels and thereby also meet RAO V.

Caps would meet RAOs by covering contaminated soil areas with uncontaminated soil, rock, or other materials such as asphalt, concrete, or geosynthetic materials. Vegetation may be established on the surface of soil caps to enhance evapotranspiration, reduce infiltration of water, and control soil erosion. Alternatively, the surface may be paved to allow for industrial end use or covered with rock armor to discourage any end use.

The cap should perform the required functions for the duration of risk. Caps must be designed for site-specific conditions, including the risks to be mitigated, ARARs, waste characteristics, available construction materials, and site environmental conditions, including climate and precipitation. Technical requirements for cap design are defined by the RAOs and the action- and chemical-specific ARARs and to-be-considered (TBC) requirements. Functional requirements for cap design must consider factors that include

- Possibility for penetration of plant roots, burrowing animals, and insects into soil and mobilization of waste to the surface

- End use, e.g., vehicular traffic load ratings

- Site surface and subsurface infrastructure that may interfere with construction
- Climate, including temperature, precipitation, insolation, evaporation, transpiration
- Potential for inadvertent human intrusion
- Subsidence of underlying materials, which can cause water ponding and increased infiltration
- Stability of the subgrade and of surface and side slopes
- Wind or water erosion
- Catastrophic events, such as earthquakes, volcanoes, or floods. The *Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement* (DOE 2002) evaluated three previous studies that examined the flooding potential of INTEC facilities. The Environmental Impact Statement concluded that portions of INTEC, including areas at the north end, could be flooded in a 100-year event; however, water velocities would be low and depths shallow.

The implementability of any capping option will be affected by tank farm loading controls and the presence of surface and subsurface infrastructure. TPR-7089 states that "Tank Farm load controls shall be established, implemented, and maintained to ensure that any loads affecting the Tank Farm vaults do not increase the load on any structural member by more than 10% above the load from at-rest soil conditions." Currently, the tops of the tanks are about 8 ft bgs; therefore, addition of even 1 ft of soil would exceed this criterion. These loading constraints are assumed to end after 2012 when grouting of tanks and vaults WM-180 through WM-190 is scheduled to be completed.

Some subsurface infrastructure will remain active after the tanks and vaults are closed. As discussed in Section 1, process lines from the WM-191 service waste diversion tank to the process equipment waste (PEW) evaporator, from the PEW evaporator to the New Waste Calcining Facility, and from other INTEC facilities to the PEW evaporator would remain active until 2035 based on current planning. Utility lines (service waste, steam, etc.) supporting those facilities and processes will also remain active. Cap design over these areas would have to accommodate the potential need for inspection, maintenance, and repair of the lines, as well as the presence of valve boxes used to control flows.

Capping would be constrained by surface infrastructure. Asphalt, concrete, and geosynthetic caps have been installed and sealed around infrastructure; however, compacted clay covers cannot be as readily installed over or around surface infrastructure. All surface infrastructure in the central tank farm is planned to be leveled to grade by 2012. Most liquid transfer lines associated with the tank farm will be removed from service by that time. However, some waste transfer lines, such as those associated with the CPP-604 tanks, PEW evaporator, and WM-191, as well as some utility lines (steam and service waste), are located within the boundary of the tank farm and will remain in service after 2012.

Capping options that may effectively meet the RAOs and ARARs for OU 3-14 are described below.

3.2.2.3.1.1 RCRA Subtitle C Cap—This type of cap is designed to meet performance objectives for RCRA Subtitle C landfill closures under 40 CFR 265.310. EPA guidance (EPA 1987) recommends a cap consisting of (top to bottom) an upper vegetated soil layer, a sand drainage layer, and a FML overlying a compacted clay barrier. A gas collection layer may be included if gas-generating wastes are capped. Nominal thickness of this type of cap is 1.5 m (4.9 ft) and addition of grading fill would increase the thickness at the crest. Figure 3-1 shows a schematic cross section of a RCRA Subtitle C cap.

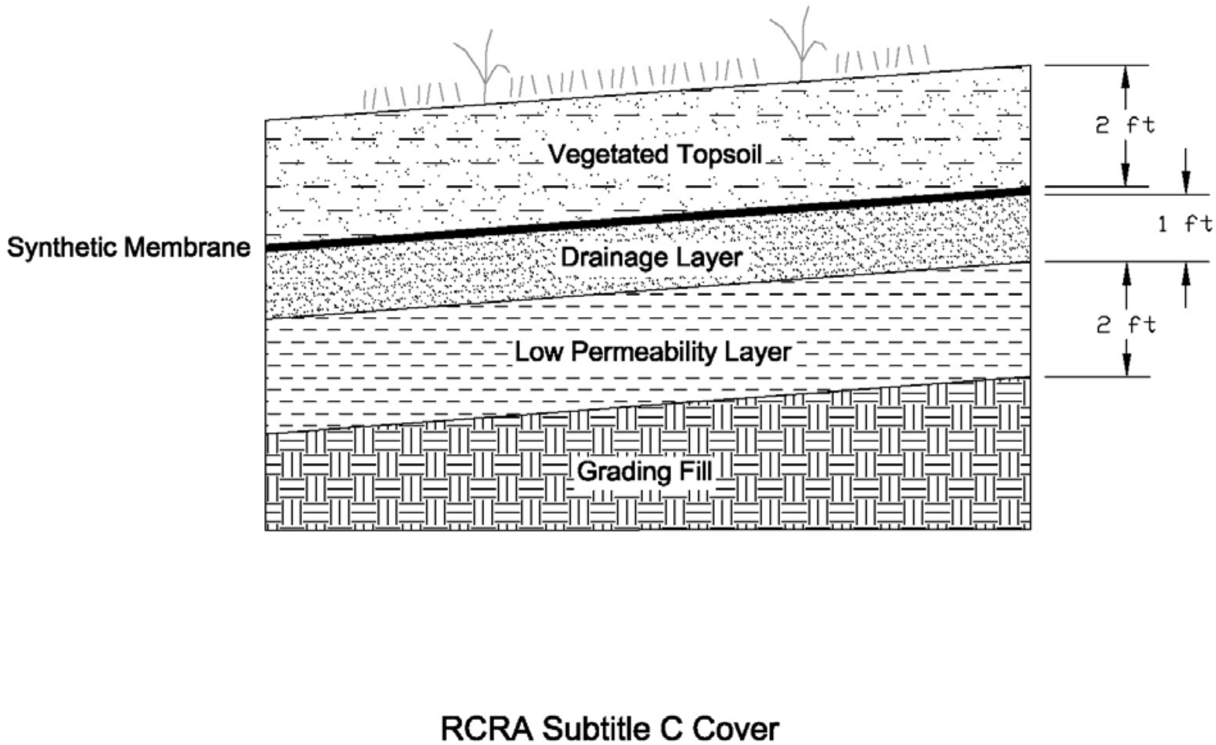

Figure 3-1. Cross section of a RCRA Subtitle C landfill cover.

This type of cap is designed to be less permeable than the bottom liner of a RCRA Subtitle C landfill and meets requirements of 40 CFR 265.310. However, other types of caps may be used if equivalent performance can be demonstrated through numerical modeling and/or site-specific large-scale lysimeter studies.

A RCRA Subtitle C cap could potentially meet RAOs identified above. This type of cap would only be technically implementable on the tank farm surface after sufficient surface infrastructure had been removed to allow for construction due to poor constructability of compacting clay and sealing geosynthetics around or over aboveground structures. Additionally, tank farm surface loading constraints would prevent construction prior to grouting of the tanks. A RCRA Subtitle C cap is therefore technically implementable on the central tank farm after about 2012 and on the entire tank farm area after about 2035.

3.2.2.3.1.2 Water Balance or Evapotranspiration Caps—Evapotranspiration (ET) caps contain a thick soil layer with a vegetated surface. ET caps are designed to manage the water balance of the capped area such that deep infiltration through the barrier to underlying contaminated soil is minimized. Precipitation onto the cap that does not run off is stored within the porosity of a thick soil layer. Soil moisture stored at shallow depths in the cover profile can be removed by direct evaporation, while deeper soil moisture can be removed by cover vegetation transpiration demand during the growing season.

The ET cap exploits the high evaporation and transpiration demands exerted by arid and semiarid climates and native plants to maintain low soil moisture contents, thereby minimizing unsaturated hydraulic conductivity and infiltration. The soil layer serves to store water to sustain plants during dry periods and also during periods when plants are inactive. Figure 3-2 shows a schematic cross section of a single-layer evapotranspiration cap (ITRC 2003).

Incorporation of capillary barriers consisting of coarse materials, e.g., gravel or cobbles, under the thick soil layer in ET covers can further reduce infiltration to underlying contaminated soil. At soil moisture contents below field capacity, water moves in the direction of greater capillary suction, expressed as negative soil moisture potential. Capillary suction is inversely proportional to both size of soil pore space and soil water content. Moisture potential in a dry layer of coarse-grained gravel and/or cobble is zero, resulting in a barrier to capillary flow between overlying and underlying finer-grained layers where pressures are negative. When overlying fine-grained soil approach saturation, moisture potential values increase to greater than zero and water will drain into and through a capillary barrier.

The capillary barrier may be actively or passively vented to remove water vapor and thereby maintain a low moisture content and may also use porous materials, e.g., sandstones or pumice, to provide additional moisture storage in the event that the overlying soil reaches saturation and drains. This variation has been called a “dry barrier” (Ankeny et al. 1997). A biobarrier typically consisting of one or more layers of gravel and cobbles may also be included; alternatively, the capillary barrier may also serve as a biobarrier. Figure 3-3 shows a schematic cross section of an evapotranspiration cover incorporating a capillary barrier.

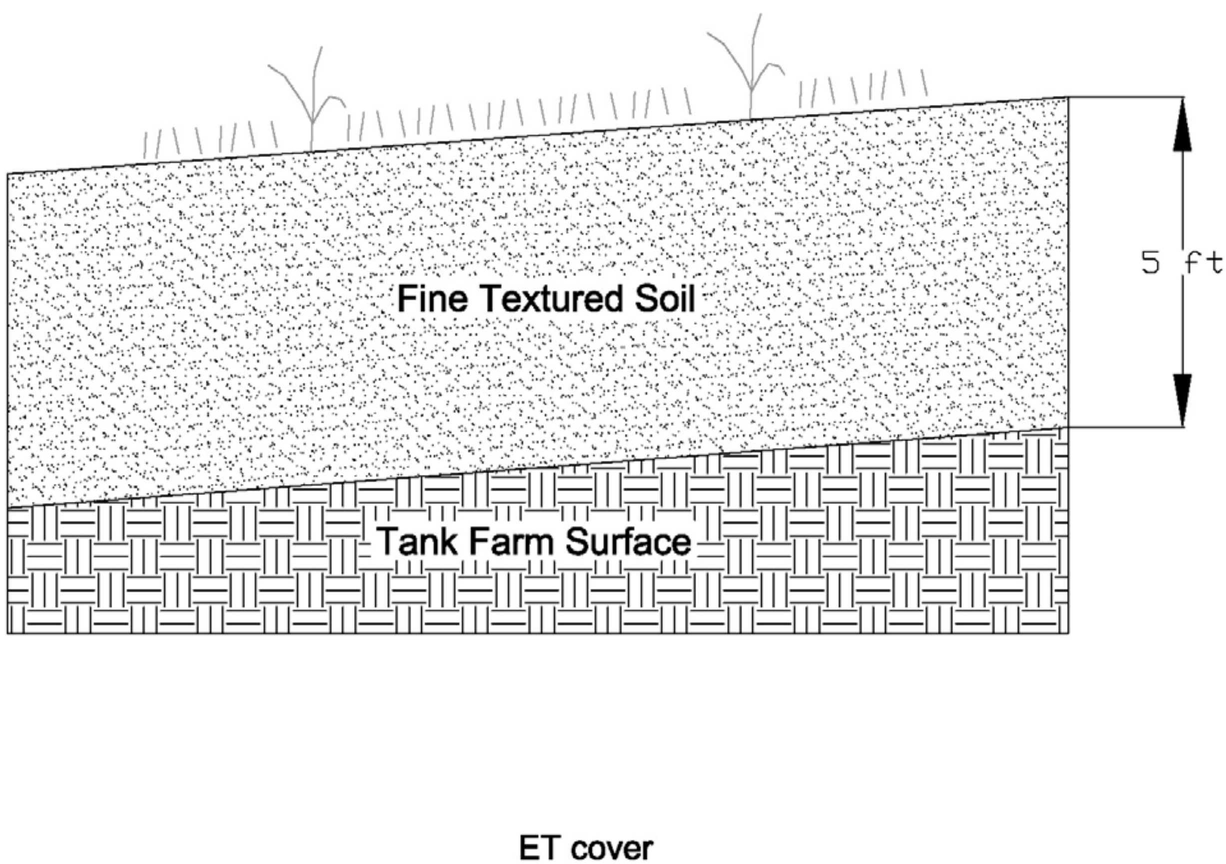

Figure 3-2. Cross section of a monolithic ET cover.

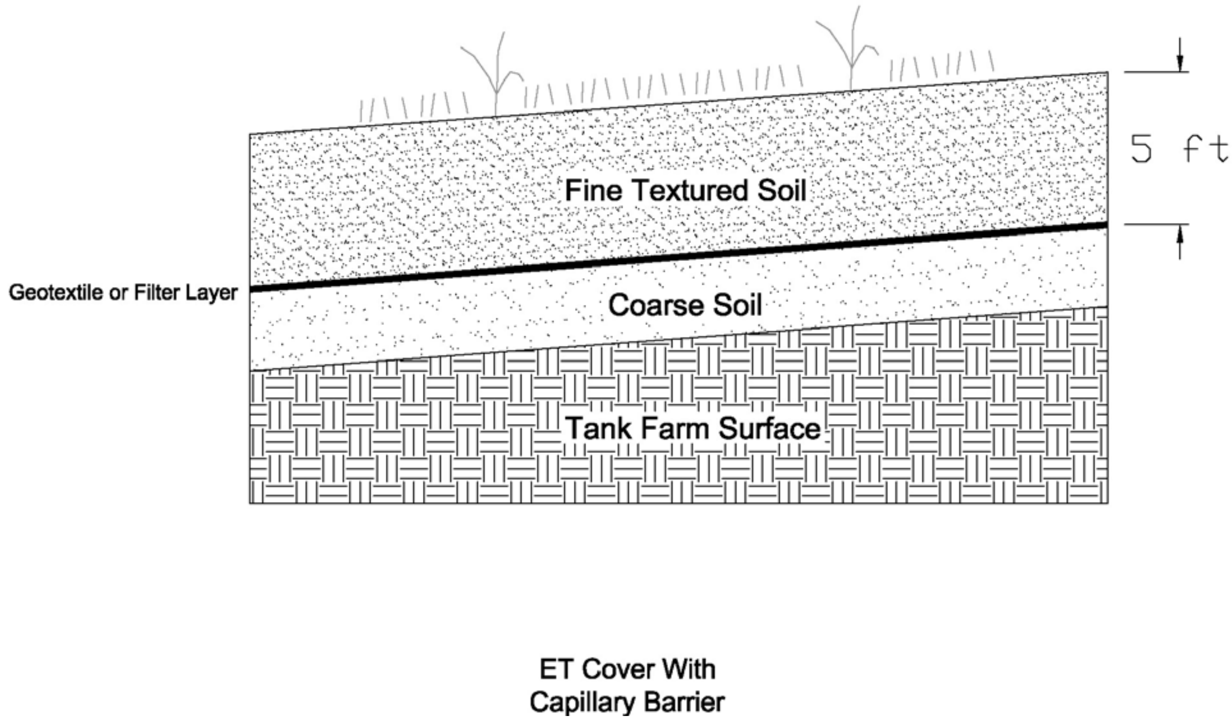

Figure 3-3. Cross section of an evapotranspiration cover incorporating a capillary barrier.

Magnuson (1993) modeled performance of proposed Radioactive Waste Management Complex (RWMC) Subsurface Disposal Area (SDA) closure covers, including the ET/capillary barrier cover design shown in Figure 3-3. The simulations were performed using UNSAT-H Version 2.0 and a combined set of weather and climate observations collected over the period 1981-1990 from the RWMC, Central Facilities Area, and the Idaho Falls and Pocatello airports.

Drainage through the ET/capillary barrier cover as modeled was extremely low and was on the order of the mass balance error of the simulations. Annual drainage through the capillary barrier for the 10-year period of the simulation ranged from 4.88E-01 cm to 3.27E-02 cm, with an average annual drainage of 1.2E-01 cm/yr. Maximum drainage occurred in the first year, based on an assumption that soil would be wetted to optimum water content (22%) for compaction during construction. This would not be required because overcompaction of soil is not desired for vegetated covers (ITRC 2003), and drainage in the first years after construction would be less.

Performance of a 7.5-ft-thick vegetated soil cover design, thicker than that shown in Figure 3-2 but otherwise similar, was also modeled by Magnuson (1993). Annual drainage through the thick soil cover for the 10-year period of the simulation ranged from 0.58 cm to 1.84 cm, with an annual average drainage of 1.07 cm. As for the ET/capillary barrier cover, maximum drainage occurred in the first year.

Flooding scenarios were also modeled for the RWMC evaluation, consisting of surface saturation for periods of 0.5 to 2 days. Neither the capillary barrier nor the vegetated soil cover design resisted drainage through the cap under flooding conditions; however, the capillary barrier appeared to reduce overall drainage more than the thick soil cover.

Field testing of a thick soil-only ET cap in the Protective Cap/Biobarrier Experiment (PCBE) 4 km north of the INTEC determined that wetting fronts reached from less than 0.2 m to over 1.2 m (3.9 ft); therefore, increasing thickness beyond 1.2 m may not improve performance significantly for vegetated soil caps.

Several features would be incorporated into the ET cover to protect the topsoil component from erosion. The top layer includes an admixture of pea gravel that will assist in armoring the barrier surface to protect it from wind erosion. Native vegetation will be established on the cover surface to further assist in reducing soil loss due to wind and water erosion. The barrier design includes sufficiently thick soil layers to provide performance margins against long-term wind or water erosion (Keck et al. 1992).

Evapotranspiration caps have been demonstrated to provide infiltration control equivalent to RCRA Subtitle C caps under some conditions (ITRC 2003; Magnuson 1993). Evapotranspiration caps would effectively reduce direct radiation exposures to future workers and may reduce flux of Sr-90 to the SRPA sufficiently to meet RAOs I and II. Evapotranspiration caps may potentially meet 40 CFR 264.310 performance objectives. Exposure to ecological receptors would be mitigated to varying degrees depending on the specific design. The coarse rock and gravel layers used in a capillary barrier design could reduce or eliminate intrusion of plant roots and burrowing insects and mammals (Keck et al. 1992). The thick soil layers of an ET cover lacking a capillary barrier would also reduce exposures to biota.

This type of cap would require a soil layer at least 4.5 ft thick to provide adequate soil moisture storage (Anderson 1997) and protection of future workers (RAO III). The cap would only be technically implementable on the tank farm surface after sufficient surface infrastructure had been removed to allow for construction. Tank farm surface loading constraints would prevent construction prior to grouting of the tanks. An evapotranspiration cap is therefore technically implementable on the central tank farm after about 2012 and on the entire tank farm area after about 2035.

3.2.2.3.1.3 Rock Armor Caps—This type of cap may include an erosion- and/or intruder-resistant rock armor surface and potentially a compacted clay barrier (DOE 1988, 1989). These caps have been used in the uranium mill tailings remedial action (UMTRA) program to stabilize uranium mill tailings. A rock-armor-only cap was used to close the SL-1 burial ground at the INL Site, with the objective of preventing human intrusion.

A rock armor cap could provide protection of future workers (RAO III) but would not reduce infiltration of water unless underlain by a compacted clay, geosynthetic clay, and/or high-density polyethelene (HDPE) membrane liner. Rock armor caps without low-permeability layers increase infiltration rates relative to background conditions because (a) evaporation demand is reduced due to the temperature and wind speed reduction at the soil surface afforded by the rock armor and (b) lack of transpiration demand in the absence of plants. The cap would only be technically implementable on the tank farm surface after sufficient surface infrastructure had been removed to allow for construction and after subsurface process lines had been removed from service. Tank farm surface loading constraints would prevent construction prior to grouting of the tanks. A rock armor cap is therefore technically implementable on the central tank farm after about 2012 and on the entire tank farm area after about 2035.

3.2.2.3.1.4 Hanford Barrier—The Hanford barrier, developed for the long-term isolation of Hanford wastes, is composed of native earthen materials, geosynthetics, polymeric asphalt, and concrete materials. The Hanford barrier is designed as a water balance system for long-term (>1,000 years) survivability in semiarid to subhumid environments (Gee et al. 1995; Wing and Gee 1994) and is designed to meet RCRA Subtitle C performance objectives. A Hanford barrier is an ET cap incorporating a capillary barrier, as well as other protective layers, designed to reduce infiltration and to result in a total cover thickness greater than 5 m (15 ft) to meet DOE Order 435.1 guidance recommending a soil barrier at least this thick over buried waste. This thickness of clean soil is assumed to allow for future residential intrusion without exceeding exposure limits.

Asphalt and concrete materials are used in the Hanford barrier below the frost depth and are protected from freeze-thaw damage, ultraviolet (UV) light, salt, chemical attack, and contact with water under most conditions. These layers could not be maintained, but functional life would be expected to be longer than when used as surface layers.

A variation of this barrier type is proposed for use as the final closure cover of the ICDF (EDF-ER-271). Figure 3-4 shows a schematic cross section of the proposed ICDF final cover.

Hydrologic performance of the proposed ICDF cover was modeled using a combination of an unsaturated flow model (SoilCover 2000) and analytical solutions for determining surface water run-off, lateral drainage, and infiltration due to cover defects. Two climatic scenarios were evaluated, a base case using average annual precipitation for a 10-year period of INL Site National Oceanic and Atmospheric Administration (NOAA) observations and an extreme case with 4 years of precipitation greater than the 90th percentile value for the INL Site NOAA observations. Infiltration through the bottom layer of the cap was less than 0.1 mm/year for all cases.

A Hanford barrier would provide adequate protection of future workers (RAO III) and would essentially eliminate infiltration of precipitation (RAOs I and II). The cap would only be technically implementable on the tank farm surface after sufficient surface infrastructure had been removed to allow for construction and after subsurface process lines had been removed from service. Tank farm surface loading constraints would prevent construction prior to grouting of the tanks. A Hanford cap is therefore technically implementable on the central tank farm after about 2012 and on the entire tank farm area after about 2035.

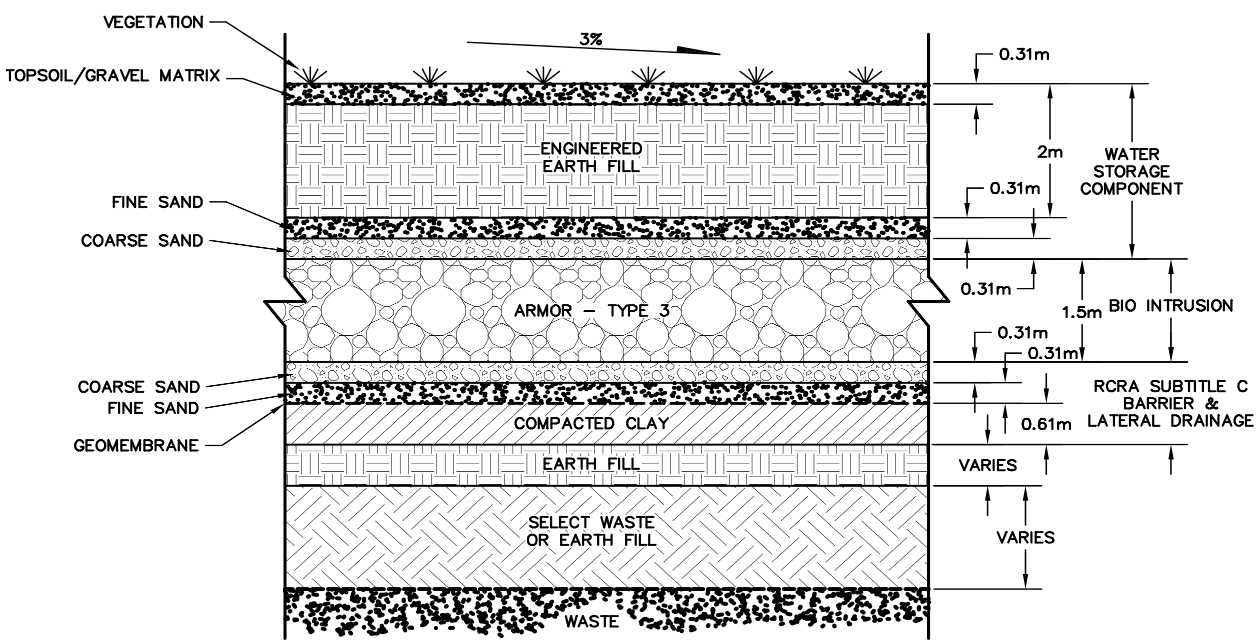

Figure 3-4. Cross section of proposed ICDF final cover.

3.2.2.3.1.5 Concrete Cap—Concrete has been used for entombment of structures, e.g., the INTEC Waste Calcining Facility (WCF), as well as for closure covers over buried low-level waste (Chang and Hanson 1990). Concrete covers may potentially inhibit human and biotic intrusion into buried waste and can reduce or eliminate infiltration into underlying waste (RAOs I and II). A concrete barrier would have to be at least 4 ft thick to meet RAO III, unless a thinner cover was determined to provide an adequate worker barrier.

Some concrete structures have survived for centuries; however, concrete is susceptible to damage or attack, including

- Physical damage, including cracking as a result of subsidence, freeze-thaw action, seismic activity, erosion and abrasion

- Chemical attack by sulfate, chloride, alkali-aggregate reaction, leaching, acids, and carbonation.

Concrete with a low water:cement ratio can have a hydraulic conductivity of less than 1E-12 cm/sec. However, the actual hydraulic conductivity of weathered concrete structures is dominated by cracks (Walton and Seitz 1991); therefore, the permeability will increase over time as weathering occurs.

Additives, including sulfur polymer cement, may reduce the effects of chemical attack, increase strength, and increase the functional life of concrete. Sulfur polymer cements are potentially more resistant to chemical attack by acids and salts than Portland-type cements. Sulfur concrete has been demonstrated to be roughly twice as strong as conventional Portland cements concrete in compressive, tensile, and flexural tests and more resistant to mineral acids and salts (McBee, Weber, and Ward 1988).

A concrete cap would be technically implementable on the tank farm surface after the high-level waste (HLW) tanks are grouted and sufficient surface infrastructure is removed. The concrete surface can be sealed around infrastructure using adhesive sealants and flexible boots; therefore, complete removal of infrastructure prior to installation would not be required.

3.2.2.3.1.6 Conventional Asphalt Cap—A conventional asphalt cap may consist of a single layer of bituminous pavement over a prepared subgrade to isolate contaminated soil, reduce infiltration, and provide a trafficable surface. An asphalt cap could potentially help to meet RAOs I and II. Asphalt caps alone would not provide an adequate worker protection barrier (RAO III). Exposures to ecological receptors (RAO V) would be eliminated as long as the asphalt was maintained.

Asphalt is susceptible to damage by mechanisms including contact with water which reduces bonding of asphalt and aggregate and may cause swelling of limestone aggregates, freeze-thaw action, fatigue cracking, UV light, salts, chemicals, petroleum, physical abrasion and others. Asphalt surfaces can protected by using a seal coating which acts as a barrier between the environment and the asphalt pavement. Coal tar emulsion sealers are typically used, which are resistant to water, gas and oil, salt, chemicals, and UV radiation. Seal coatings can significantly reduce the hydraulic conductivity of asphalt. Seal coatings must be reapplied relatively frequently to remain effective.

Areas CPP-28, -31, and -79, which were unpaved/gravel surfaces within the tank farm, were sealed with asphalt in 2004 to reduce water infiltration and divert surface water toward the storm water collection system as part of the TFIA, as described in DOE-NE-ID (2005). Select areas outside the tank farm were also covered with asphalt which sloped in the direction of nearby concrete-lined storm water collection ditches. These areas are located along the west side of Beech Street between Cypress Avenue and Olive Avenue, on both sides of Olive Avenue from Beech Street to Building CPP-659, and north of the tank farm along Cypress Avenue and Cedar Street.

Areas within the tank farm that were covered with asphalt included soil contamination area CPP-31 (10,428 ft^2) and combined soil contamination areas CPP-28 and CPP-79 (4,029 ft^2). Surface water in these areas drains to discharge piping and then to concrete-lined storm water collection ditches along the perimeter of the tank farm. All asphalt within the tank farm was seal-coated twice to ensure an adequate infiltration barrier.

An extended area of asphalt cap would be technically implementable on the tank farm surface at present. The asphalt cover constructed during the TFIA used hand-compacting machines, instead of heavier equipment, to meet tank farm loading restrictions. The asphalt surface can be sealed around infrastructure using adhesive sealants and flexible boots; therefore, removal of infrastructure prior to installation would not be required.

3.2.2.3.1.7 MatCon Asphalt Cap—MatCon™ asphalt has been used for RCRA Subtitle C-equivalent closures of landfills and soil contamination sites. MatCon™ is produced using a mixture of a proprietary binder and a specified aggregate in a conventional hot-mix asphalt plant. The EPA Superfund Innovative Technology Evaluation (SITE) program evaluated MatCon™ in 2003 (EPA 2003) with respect to permeability, flexural strength, durability, and cost. EPA determined that the as-built permeability of <1E-07 cm/sec was retained for at least 10 years with only minor maintenance and that MatCon™ had superior mechanical strength properties and durability. However, installation of MatCon™ would require higher compaction energy than hand compactors used to install conventional asphalt for the TFIA and could therefore likely only be implemented on the tank farm after the HLW tanks were grouted.

A MatCon asphalt cap could potentially help to meet RAOs I and II. A MatCon asphalt cap alone would not provide an adequate worker protection barrier (RAO III). Exposures to ecological receptors (RAO V) would be eliminated as long as the asphalt was maintained.

3.2.2.3.1.8 Flexible Membranes—Flexible membranes are single layers of relatively impermeable polymeric plastic (HDPE and others). Flexible membranes are a component of a RCRA Subtitle C cover and, potentially, of other types and may also be used alone. Flexible membranes are laid out in rolls or panels and welded together. The resulting membrane cover is essentially impermeable to transmission of water unless breached. Flexible membranes can be sealed around surface infrastructure using waterproof sealants.

Flexible membranes must be protected from damage to remain impermeable. Flexible membranes are subject to damage and/or leakage due to excessive heat, freezing, temperature cycling, punctures, poor welds, tearing, shearing, UV or other radiation exposure, and chemical incompatibilities. A membrane liner was installed on the tank farm in 1977 and covered with about 1.5 ft of soil. The effectiveness of the existing liner with respect to reducing infiltration is uncertain. Flexible membrane liners would not reduce direct radiation exposures.

3.2.2.3.2 Surface Water Management—Surface water management promotes surface water run-off, reduces recharge of the vadose zone, and limits leaching and infiltration of surface soil contaminants to groundwater. Surface water management would not prevent external exposures to future workers (RAO III). Surface water management could potentially help meet RAO I by reducing infiltration rates sufficiently that COC flux rates did not result in concentrations exceeding applicable groundwater quality standards in the SRPA after 2095. Surface water management would have minimal reduction of exposures to ecological receptors (RAO V). Surface water management options are summarized below.

3.2.2.3.2.1 Operate and Maintain Tank Farm Interim Action—This option would consist of operation and maintenance (O&M) of the TFIA, as described in DOE-ID (2005). The TFIA was implemented as part of the "Agreement to Resolve Dispute" (DOE 2003) and was designed to reduce infiltration of precipitation through release Sites CPP-28, CPP-31, and CPP-79 by at least 80% of the average annual precipitation.

The TFIA included

- An evaporation pond with double liner, perimeter fencing, and leak detection system
- Concrete-lined ditches and culverts in and around the tank farm extending to the evaporation pond
- A lift station at Olive Avenue (CPP-1792) to pump storm water into the evaporation pond
- Asphalt coverings over selected areas within 150 ft of the tank farm
- Asphalt surface-seal over release Sites CPP-28, -31, and -79 in the tank farm
- A drainage system from the surface-sealed areas to the concrete-lined ditches.

O&M of the TFIA would include (DOE-ID 2005)

- Inspection and repair as needed of asphalt areas
- Inspection, clearing, and repair of discharge pipes, culverts, and storm drains
- Inspection, maintenance, and repair of the lift station
- Inspection and repair of the evaporation pond and sediment removal, as required, and disposal in ICDF.

The TFIA is currently operated and maintained by INTEC Operations. O&M of the TFIA would become part of the OU 3-14 remedial action, if selected.

3.2.2.3.2.2 Lining the Big Lost River Channel—Lining of the Big Lost River channel would be implemented outside the tank farm but could affect recharge of the deep vadose zone and perched water underlying the tank farm. This technology is under consideration as part of the OU 3-13 Group 4 remedial action and is not considered further herein.

3.2.2.3.3 Subsurface Barriers—Subsurface barriers may potentially limit downward migration of COCs in infiltrating water by formation of a physical barrier to flow. Subsurface barriers must be implemented with surface barriers to avoid "bathtubbing."

Subsurface barriers would not prevent direct radiation exposures to future workers (RAO III). Subsurface barriers could potentially reduce Sr-90 migration from the tank farm alluvium to the SRPA by reducing infiltration rates below the contaminated alluvium (RAOs I and II). Subsurface barriers would not prevent exposure of ecological receptors (RAO V).

Literature review of potential horizontal and vertical subsurface barriers, including freeze walls, jet grouted barriers, permeation grouted barriers, hydrofracturing, slurry walls, sheet pilings, and permeable reactive walls, indicated that these technologies would not be effective in meeting RAOs and/or would not be technically implementable. Horizontal and vertical subsurface barriers are therefore not considered further in this FS for tank farm soil.

3.2.2.4 In Situ Treatment. In situ treatment may potentially reduce the mobility or volume of OU 3-14 COCs, including Cs-137 and Sr-90. In situ treatment could potentially reduce or prevent external exposures to future workers (RAO III) by extracting Cs-137 for ex situ treatment and disposal. In situ treatment to prevent Sr-90 migration from the tank farm alluvium would require extracting Sr-90 for ex situ treatment and disposal, converting the strontium species present in the alluvium to a less mobile species, macroencapsulating the Sr-90 in an inert matrix, or modifying the alluvial soil properties to reduce infiltration rates and thereby Sr-90 flux rates (RAOs I and II). In situ treatment would not be implemented solely to prevent exposure of ecological receptors (RAO V) but would mitigate exposures to varying degrees depending on the type of treatment used. Potential biological and physicochemical methods of in situ soil treatment are discussed below.

3.2.2.4.1 Biological Treatment—Biological treatment uses vegetation or microbes to extract or convert COCs to less mobile forms. Several types of biological treatment methods are discussed below.

3.2.2.4.1.1 Phytoremediation—Phytoremediation uses plants to remediate various organic and inorganic contaminants in solid and/or liquid media. These technologies can be implemented either in situ or ex situ. Inorganic contaminants that can be potentially remediated include salts, metals, metalloids, and radionuclides. The affected media that phytotechnologies can be used to address include soil, sediment, groundwater, and surface water (ITRC 2001). Phytoremediation could potentially be used to remove Cs-137 from soil to a concentration of at least 92 pCi/g and a depth of at least 4 ft bgs.

Plant root systems take up essential inorganic plant nutrients, including N, P, K, Ca, Mg, S, Fe, Cl, Zn, Mn, Cu, B, and Mo, as dissolved constituents in soil moisture. These elements are required by the plant for growth, development, or reproduction and are acquired either passively in the transpirational stream or actively through transport proteins associated with the root membrane. Once inside the root system, the dissolved nutrients can be transported throughout the remainder of the plant through the vascular system of the plant known as the xylem.

In addition to the essential nutrients, other nonessential inorganics, including Cs and Sr, can be taken up as well. Because these other inorganics are not essential to the plant and may represent potential toxins at high concentrations, the plant also contains various mechanisms to sequester or stabilize these extraneous inorganics and prevent translocation into the more sensitive, terrestrial portion of the plant. One primary mechanism is to sequester the nonessential inorganic into the vacuoles of the plant cells, which act, in part, as a storage receptacle for the plant.

Another mechanism is to bind these inorganics in the soil or on the root surfaces, preventing them from entering into the plant system. The uptake and accumulation of inorganic elements into the plant tissues is known as phytoaccumulation. The primary mechanisms for the remediation of inorganics are based on the ability of the plants to accumulate or stabilize the inorganic constituents.

The relative ability of a plant to take up a chemical from the soil or groundwater and translocate it to its shoots is described by the root concentration factor (RCF) and transpiration stream concentration factor (TSCF) for the chemical. Respectively, the RCF and TSCF are measures of the root concentration and xylem sap concentration of a contaminant relative to the concentration in the external soil moisture solution. Higher RCF and TSCF values are an indication of enhanced contaminant uptake by plants. Inorganic contaminants that partition readily into the soil moisture solution are more readily taken up in the transpiration stream than contaminants that partition more readily to soil.

The uptake efficiency depends on the soil properties, physicochemical properties of the contaminant in the soil, chemical speciation, and the plant itself. Certain plants called hyperaccumulators absorb unusually large amounts of metals in comparison to other plants and the ambient metal concentration. For a plant to be classified as a hyperaccumulator, it must be able to accumulate at least 1,000 mg/kg (dry weight) of a specific metal or metalloid (for some metals or metalloids the concentration must be 10,000 mg/kg) (Baker, Brooks, and Reeves 1988). Hyperaccumulators are selected and planted at a site based on the type of metals present, the concentrations of these constituents, and other site conditions. As a general rule, readily bioavailable inorganics for plant uptake include cadmium, nickel, zinc, arsenic, selenium, and copper. Moderately bioavailable metals are cobalt, manganese, and iron; whereas lead, chromium, and uranium are not very bioavailable. Lead can be made much more bioavailable by the addition of chelating agents, such as ethylene diamine tetra-acetic acid to soil (Schnoor 1997). Similarly, the availability of uranium and Cs-137 can be enhanced using citric acid and ammonium nitrate, respectively (Dodge and Francis 1997; Riesen and Brunner 1996).

A field test was performed to determine the ability of three plant species to extract Cs-137 and Sr-90 from contaminated soil (Furhmann et al. 2002). Redroot pigweed (*Amaranthus retroflexus* L.), Indian mustard (*Brassica juncea* [L.] Czern.), and tepary bean (*Phaseolus acutifolius* A. Gray) were planted in soil that was contaminated by radionuclides in the 1950s and 1960s. Concentration ratios for Cs-137 for redroot pigweed, Indian mustard, and tepary bean were 2.58, 0.46, and 0.17, respectively, where concentration ratio is the slope of the regression line obtained by plotting the concentration of the radionuclide in the dried plant against its concentration in soil.

Concentration ratios for Sr-90 were substantially higher: 6.5, 8.2, and 15.2, respectively. The greatest accumulation of both radionuclides was obtained with redroot pigweed, even though its concentration ratio for Sr-90 was the lowest, because of its relatively large biomass. There was a linear relationship between the Cs-137 concentration in plants and its concentration in soil only for redroot pigweed. Uptake of Sr-90 exhibits no relationship to Sr-90 concentrations in the soil.

Figure 3-5 shows normalized estimates of removal of initial soil activity as a function of time using the data generated in this study. Assumptions include that the top 15 cm (the plowed layer) of the soil will be remediated, that the concentration ratio and biomass produced are constant over time, that redroot pigweed is used, and that contaminant removal from soil follows first-order kinetics according to the following equation:

$$C_t = C_0 e^{-kt} \tag{1}$$

where

C_t	=	concentration of the contaminant after phytoremediation for time t
C_o	=	initial concentration of the contaminant
k	=	(plant mass per year per square meter/soil mass) × concentration ratio
t	=	time of remediation in years.

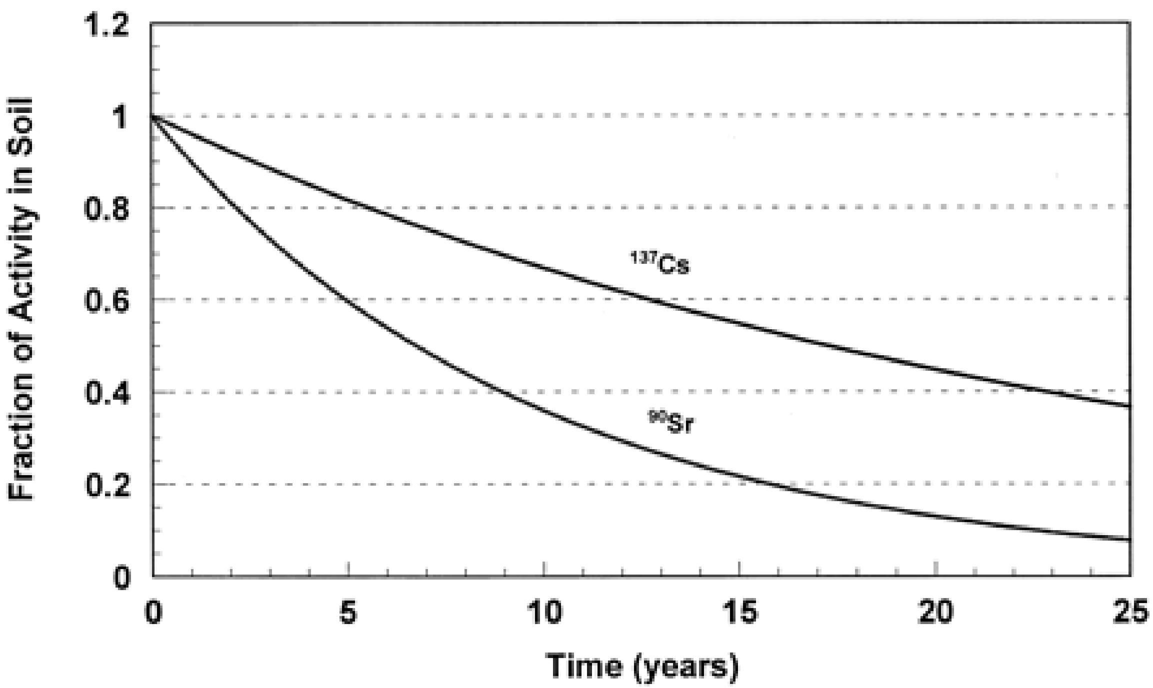

Figure 3-5. The fraction of Cs-137 and Sr-90 remaining in soil as a function of time, not accounting for radioactive decay (Furhmann et al. 2002).

Seven years would be required for 50% removal of Sr-90 and 18 years for Cs-137 assuming two crops of redroot pigweed per year, not including radioactive decay that would occur during the period.

Greenhouse studies with the same soil reported enhanced uptake of Cs-137 by plants grown in an ammonium nitrate–treated soil; however, no increase in uptake of Cs-137 in shoots of plants grown in field cells as a result of ammonium addition was observed. The difference between the greenhouse result and the field work was suspected to be related to the shorter residence time of the solution in the open system of the field experiment.

Phytoremediation was selected for remediation of Cs-137 in soil at eight sites at Argonne National Laboratory-West at the INL Site in 1998. Initial concentrations of Cs-137 were 30.5 pCi/g, only slightly above the PRG of 23.3 pCi/g. A field demonstration using *Kochia scoparia,* a species related to Indian mustard and canola, indicated a first-year uptake rate of 3.5%, calculated as the concentration of Cs-137 in the harvested plant matter divided by the initial soil concentration (Lee 2000). An Explanation of Significant Differences was signed in 2002, changing the remedy to removal and disposal, based on a change in the end use to wastewater disposal.

Entry and Watrud (1998) found that Alamo switchgrass accumulated 44% and 36% of the total amount of Sr-90 and Cs-137 initially present in soil, respectively, after five harvests. Initial soil concentrations of both radionuclides were about 3,000 pCi/g. Most of the Cs-137 uptake was observed to occur in the first 3 weeks of growth, while most of the accumulation of Sr-90 occurred in the last 2 weeks of growth. Plant uptake rates declined as soil concentrations declined.

The specific phytotechnology mechanism used to address specific contaminants is dependent not only on the type of constituent and the media that is affected but also on the remediation goals. Phytoremediation to reduce exposures of future workers at the tank farm would require phytoaccumulation of Cs-137 in plant tissues, with subsequent harvesting, volume reduction, and disposal of the plant materials. Implementation of phytotechnology involves consideration of tank farm soil, specific plant types to uptake Cs-137, plant nutritional needs, plant climatic requirements, and time required to attain remediation goals (RGs).

Specific constraints on implementation of phytoremediation at the tank farm include

- Growth habit of plants (annual, biennial, or perennial).
- Requirements for supplemental water, which may increase perched water recharge.
- Mobilization of other contaminants by excessive irrigation, addition of chelating agents or surfactants, chemical transformation of the contaminant to a more mobile form, or pH manipulation.
- Slow plant growth rates.
- Contaminant uptake rates may slow as soil concentrations decline, resulting in nonattainment of RGs.
- Dependence on climate, growth season.
- Susceptible to infestation and diseases.
- May be difficult to establish/maintain vegetation.
- May be difficult to control spread of nonnative plants.
- Slow/shallow root penetration. The effective range for plants to affect contaminants is dependent on the rooting depth of the plant system. Typical lawn-type grasses generally produce roots down to 1 ft bgs. Arid zone species are known for their deep roots and can yield systems that are 10 to 15 ft bgs.
- Limited contaminant mass transfer into root zone.
- Phytotoxicity of contaminants.
- Limited database and performance data available.
- Potential transfer to and bioaccumulation in the ecosystem.
- Monitoring requires soil analysis for Cs-137 and nutrients, potentially also monitoring of other ecological receptors to assess transfer to the food chain.
- Disposal of harvested plants likely requires compaction or incineration prior to landfilling at ICDF.
- Plant success in high-gamma-activity soil would have to be determined in field trials.
- Tank farm loading constraints on use of planting and harvesting equipment before tanks are grouted.

Phytoremediation for remediation of Cs-137 in tank farm soil is retained for further consideration. Phytoremediation for remediation of Sr-90 at CPP-31 is not considered further due to low technical implementability, based on depth of contamination and presence of extensive subsurface infrastructure.

3.2.2.4.1.2 Ureolytically Driven Coprecipitation In Calcite—Immobilization of Sr-90 in calcite is a potential remediation approach for systems that are already saturated with respect to calcite. An approach that is under development is based on the potential for in situ hydrolysis of added urea by native environmental microorganisms, resulting in generation of bicarbonate and an increase in pH, which promote the precipitation of calcite (Fujita et al. 2000). If Sr is present in the system, it can be incorporated into the calcite by substitution for Ca ions in the calcite lattice (Fujita et al. 2000; Tesoriero and Pankow 1996; Pingitore and Eastman 1986; Pingitore et al. 1992). Alternatively, Sr that is adsorbed to mineral surfaces can be encapsulated by an overlying layer of calcium carbonate precipitate. This approach is attractive in a calcite-saturated environment such as the SRPA (McLing 1994; Tobin et al. 2000), where any Sr-90 immobilized by this mechanism should remain stable following cessation of remediation activities and return to ambient conditions. Development to date of this remediation technology has been limited to laboratory demonstrations of feasibility in homogeneous (water only) systems using pure bacterial cultures (Fujita et al. 2000, 2004) and to limited field tests showing that dilute carbon additions to the SRPA can result in enhanced ureolytic activity in groundwater (Y. Fujita, Idaho National Laboratory, personal communication). To date, no field trials have been performed to prove that Sr-90 mobility can be reduced by this technology nor have any tests been conducted to evaluate its feasibility in unsaturated systems analogous to the INTEC alluvium. Modifications to the basic approach developed for groundwater are likely to be necessary to adapt to the conditions of the alluvium, particularly the low water content and the typical “patchiness” of the microbial community in unsaturated systems (Kieft et al. 1993).

This technology has not been demonstrated in unsaturated media at bench- or pilot-scale and therefore will not be retained.

3.2.2.4.1.3 Microbial Degradation of Gas-Phase Organic Phosphate Compounds and Phosphate Mineral Precipitation—Studies have demonstrated that subsurface bacteria can use gaseous tri-ethyl phosphate as a source of inorganic phosphate (Brockman et al. 1995; Palumbo et al. 1995). Separately, it has also been shown that Sr^{2+} reaction with aqueous phosphate can immobilize strontium as a phosphate mineral. The combination of these two processes (i.e., bacterially mediated phosphate generation from tri-ethyl phosphate, and subsequent reaction of the phosphate with strontium) for Sr-90 remediation has, however, not been demonstrated in laboratory studies. Consequently, this remediation option will not be retained.

3.2.2.4.2 Physicochemical Treatment—Physicochemical treatment employs physical chemistry to remove contaminants, to modify the soil environment, or to produce a physically and chemically stable waste form. The in situ physicochemical technologies discussed in this section include liquid atomized apatite injection, aqueous phosphate addition, aqueous carbonate/hydroxide addition, carbon dioxide gas injection, reduction and precipitation of metals using hydrogen sulfide gas, reduction and precipitation of metals using dithionate, soil vapor extraction, solidification/stabilization, soil flushing, and electrokinetic soil processing.

3.2.2.4.2.1 Liquid Atomized Apatite Injection—This technology was described previously as a potential permeable reactive barrier; however, it is also potentially applicable as an in situ treatment for the contaminated alluvial soil and is retained as such.

3.2.2.4.2.2 Aqueous Phosphate Addition—Precipitation of phosphate minerals containing Sr is attractive because of their low solubility. However, metal remediation based on apatite has generally involved the use of solid apatite amendments (Seaman, Meehan, and Bertsch 2001). Addition of aqueous phosphate to promote the formation of phosphate minerals has a number of disadvantages. Delivery of liquid amendments in an unsaturated system is difficult to control to the degree necessary for the amendments to be superimposed on zones of Sr contamination. If the subsurface structure is similar to the structure that existed when the initial contamination events occurred, it is possible that addition of liquid amendments injected at the same points of entry as the contaminants might travel by the same paths. However, this is speculative, and the highly acidic nature of the Sr-bearing wastes suggests that flow paths are likely to have been altered by dissolution and precipitation of carbonates and other minerals. Also, addition of phosphate-bearing amendments with the intention of forming precipitates could alter flow paths as well. Soluble phosphate amendments, such as phosphoric acid, have been tested (Melamed et al. 2003) although under conditions that are not representative of INTEC (e.g., shallow soil tests with physical mixing). In addition, the presence of calcite in the INTEC soil may preclude being able to deliver liquid phosphates significant distances. Therefore, direct addition of liquid phosphate amendments at this time must be considered to be in a developmental stage. The use of phosphate minerals to immobilize metal contaminants has, however, been shown to significantly reduce metal mobility if the desired in situ reactions take place. One potential disadvantage to the use of phosphate amendments is the potential for mobilizing other contaminants such as arsenic (Martin and Ruby 2003), but this has not been raised as an important issue at INTEC.

The use of liquid-phase phosphate amendments can be considered to be potentially viable at INTEC; however, adequate information is not available to estimate effectiveness and implementability. Movement of liquids in the contaminated alluvium must be controlled and prevented from mobilizing contaminants. Therefore, this technology is screened from further consideration.

3.2.2.4.2.3 Aqueous Carbonate/Hydroxide Addition—Coprecipitation of Sr-90 with calcite is one approach to retarding its migration through the vadose zone. Coprecipitation of metals (Tesoriero and Pankow 1996; Rimstidt, Balog, and Webb 1998) and radionuclides (Curti 1999) into calcite is well established. Coprecipitation with calcite may be feasible at the INL Site where soil with significant amounts of calcite exists. Tesorieo and Pankow (1996) report increases in apparent retardation factors for Sr by factors of 8 to 9 at higher precipitation rates compared to lower precipitation rates.

Coprecipitation of Sr-90 can be induced by increasing the saturation index of calcite through the addition of water with relatively high carbonate concentration (added as Na_2CO_3 or $NaHCO_3$ salts). By adding CO_3^{2-} (or HCO_{3-}), the pH of the soil water will increase and the solubility of calcite will decrease, inducing precipitation of a calcite solid solution with a mole fraction, X, of Ca^{2+} and a mole fraction, (1-X), of Sr^{2+}:

$$XCa^{2+} + (1-X)Sr^{2+} + CO_3^{2-} = (Ca_XSr_{1-X})CO_3. \tag{2}$$

The thermodynamic and kinetic considerations of such solid solutions are outlined in the technical literature (Tesoriero and Pankow 1996). Potential advantages of using aqueous carbonate solutions in the vadose zone for the coprecipitation of Sr-90 include the low cost of the carbonate/bicarbonate salts and the relative simplicity of the chemistry. Potential disadvantages of this approach, however, are numerous. They include

- The difficulty of delivering the reagents to the target contaminated zones, due to the nonlinear dependence of the flow parameters on water content and the high likelihood that preferential flowpaths will cause the solutions to bypass these target areas

- The possibility that even if the reactants can be delivered to the contaminated zones, the rate of advective transport will be greater than the rate of reaction, resulting in little precipitation as the solutions quickly pass through the target zones

- The potential for the addition of water to the system to significantly increase the migration of contaminants through the alluvium

- Interference with activities at the INTEC tank farm.

The disadvantages of this method are significant enough to eliminate it from further consideration for treatment of the OU 3-14 alluvium.

3.2.2.4.2.4 CO_2 Gas Injection and Coprecipitation of Metal Carbonates— As noted previously, coprecipitation of metals and radionuclides into calcite is well established and may be a feasible remediation option at the INL Site, where significant amounts of calcite already exist in the subsurface. An alternative to the addition of aqueous solutions to direct calcite precipitation is the manipulation of the soil gas composition. By adding CO_2 gas, the pH of the soil water will decrease and the solubility of calcite will increase as follows:

$$CaCO_3 + H_2O + CO_{2(g)} = Ca^{2+} + 2HCO_3^- \tag{3}$$

The additional Ca^{2+} in the soil water can solubilize sorbed Sr on an exchanger (≡Sr) via

$$\equiv Sr + Ca^{2+} = \equiv Ca + Sr^{2+} \tag{4}$$

If the Ca^{2+} concentration is insufficient to remove the Sr from the exchanger, a small amount of ammonia can be added to the gas mixture to generate NH_4^+ in the soil water to displace the Sr. Purging with another gas, such as air or N_2, will then increase the pH, inducing precipitation of a calcite solid solution with a mole fraction, X, of Ca^{2+} and a mole fraction, (1-X), of Sr^{2+}:

$$XCa^{2+} + (1-X)Sr^{2+} + 2HCO_3^- = (Ca_XSr_{1-X})CO_3 + CO_{2(g)} + H_2O \tag{5}$$

Key benefits of using reactive gas amendments in the vadose zone for the coprecipitation of Sr-90 in calcite include

- The relatively low costs of delivering gases to the vadose zone

- The fact that, due to the large diffusion coefficients of gases, most of the unsaturated sediments that are not fine-grained can be treated in spite of subsurface heterogeneity

- The lower potential (compared to aqueous amendments) for gases to mobilize soil water and associated contaminants

- Minimal impacts on tank farm closure activities.

Several considerations must be investigated prior to implementation of a treatment strategy based on reactive gases in the vadose zone at INTEC. These include

- Whether the vadose zone geochemical composition at INTEC is conducive to precipitation of calcite by gas phase manipulation

- What gas phase compositions will achieve a sufficient sequestration of Sr
- Potential mobilization of colloidal materials in the vadose zone as a consequence of treatment
- The presence of sufficient water to achieve the needed perturbations in the system geochemistry.

These issues have yet to be addressed and the technology remains unproven in the laboratory much less in the field. This option is retained for consideration.

3.2.2.4.2.5 Reduction and Precipitation of Metals Using Hydrogen Sulfide Gas—Hydrogen sulfide gas has been used to create reducing conditions in situ with the expectation that reducible metals would form insoluble mineral phases (Thornton and Amonette 1999). As mentioned earlier, Sr is not sensitive to changes in redox state; therefore, the use of hydrogen sulfide gas, or other gas-phase reductants, is not applicable for Sr contamination at INTEC. However, in the report by Thornton and Amonette (1999), they pointed out that after hydrogen sulfide treatment of chromate-contaminated sediments, under laboratory conditions, chromate was effectively immobilized but also remained largely in the oxidized state. The authors proposed that treatment with hydrogen sulfide could have formed other mineral phases that immobilized Cr(VI) by encapsulation. This might be expected if iron in the native minerals is reduced, mobilized, and re-precipitated under oxidizing conditions. Rapidly precipitated iron oxi-hydroxides generally have high surface areas and high capacity for adsorbing trace metals such as Sr. However, this possibility is speculative at this point, and there may be other unintended consequences for mobilizing contaminants at INTEC that will have to be considered. One of the general disadvantages to immobilizing metal contaminants by generating reducing conditions is that either the reducing conditions must be maintained indefinitely or re-oxidation must be slow. If Sr were encapsulated by precipitated iron oxides, this would not be a problem and immobilization could be effective for the time required for decay of Sr-90 to reduce the hazard. The advantage to hydrogen sulfide gas treatment is that it may be a more effective treatment option than liquid amendments applied to unsaturated media. A significant disadvantage is the health risk associated with use of hydrogen sulfide in uncontained environments. Biological production of hydrogen sulfide in situ has also been proposed and could reduce the health hazard to some degree, but creating the environment necessary for such biological activity at INTEC is likely impossible due to the low water content and difficulty in reducing oxygen flux in the unsaturated media. Because of the potential health risks, along with the uncertainty about any potential mechanisms for Sr immobilization, hydrogen sulfide gas is not retained as a treatment option for the OU 3-14 alluvium.

3.2.2.4.2.6 Reduction and Precipitation of Metals Using Dithionite— Reduction of contaminants in situ using dithionite (added as an aqueous solution) to form insoluble mineral phases has been demonstrated in laboratory experiments and in a field test at the Hanford Site (Fruchter et al. 2000). The field test at Hanford was designed to reduce chromate although the authors have also proposed using dithionite to promote the in situ destructive reduction of chlorinated solvents. The mechanism for metal reduction is proposed to occur through initial reduction of iron (III) to iron (II) in the sediments, which subsequently reduces contaminants and re-oxidizes the iron. However, as mentioned above, Sr is not sensitive to changes in redox state, and whether reduction and re-precipitation of iron could help reduce contaminant mobility through adsorption on reactive, high-surface-area iron oxides is unknown. Due to the previously mentioned challenges associated with aqueous additions to the vadose zone and the uncertainty regarding potential mechanisms for Sr immobilization, this option is not retained for treatment of the OU 3-14 alluvium.

3.2.2.4.2.7 Soil Vapor Extraction—Soil vapor extraction (SVE) is a demonstrated, commercially available technology for removing volatile constituents from soil. SVE would not effectively remove Sr-90 or Cs-137 from soil; however, SVE removes soil moisture vapor and reduces soil moisture content, reducing unsaturated moisture flow rates and thereby contaminant flux rates in the unsaturated zone. This technology was selected for remediation of Tc-99 in unsaturated soil at Hanford in 2004 (Truex 2004).

Figure 3-6 (Anderson and Woessner 1992) shows the relationship between soil moisture content and hydraulic conductivity for a range of soil types. Soil moisture tension increases with decreasing soil moisture content (Figure 3-6a), while hydraulic conductivity decreases with increasing soil moisture tension. Stated simply, as the soil becomes dryer, the hydraulic conductivity decreases.

Yoon, Valocchi, and Werth (2003) modeled soil moisture content as a function of time for a number of values of air removal rate and influent air relative humidities for a sandy soil from the Hanford Site using a finite element model. Figure 3-7 shows results for the fractional water saturation as a function of distance from the venting well and of time for a gas flow rate of 100 m d^{-1} and an influent air relative humidity of 25%. Both Case 1 and Case 2 used a gas flow rate of 100 m d^{-1} and an influent relative humidity of 25%. Case 1 used an initial water content of 20% of saturation while Case 2 used a lower initial water content of saturation of 4.56% of saturation. After 100 days, for Case 1, soil moisture contents at 1 m radial distance from the venting well had decreased to about 16% of saturation and, for Case 2, to about 0.5%.

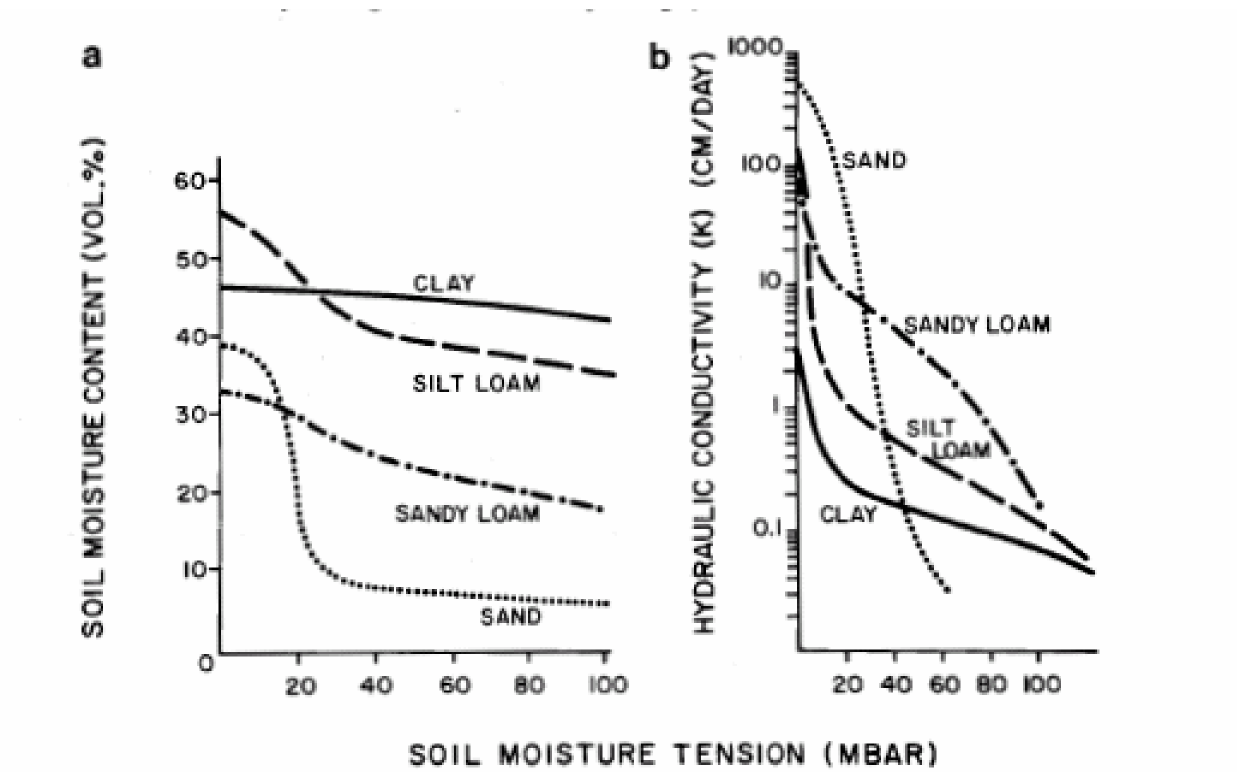

Figure 3-6. Representative characteristic curves showing the relation (a) between moisture content and soil moisture tension and (b) between hydraulic conductivity and soil moisture tension for several soil types (Anderson and Woessner 1992).

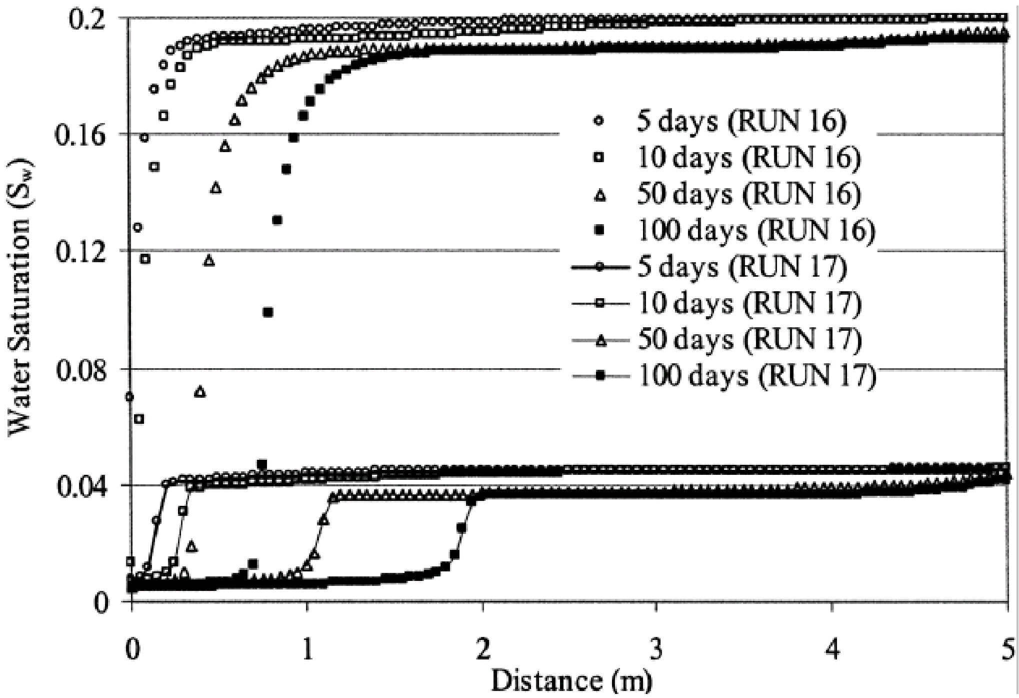

Figure 3-7. Spatial profile of water saturation at different times for Case 1 (symbols only) and Case 2 (symbols with lines).

The effectiveness of SVE in reducing soil moisture contents at the tank farm to sufficiently low levels to significantly reduce unsaturated flow would have to be evaluated in a field demonstration. The technology is commercially available and could be implemented at present. The technology would have to be implemented in combination with recharge controls, e.g., capping and/or OU 3-13 Group 4 remedies, to be effective. The required duration of operations would depend in part on the effectiveness of recharge controls. SVE is retained as an in situ treatment technology pending field demonstration.

3.2.2.4.2.8 Solidification/Stabilization—Solidification and stabilization technology is currently used to treat a wide variety of metal- and radionuclide-contaminated sites. Stabilization and solidification may reduce mobility of soil contaminants while encapsulating the waste in a monolithic solid of high structural integrity.

Grout mixtures are typically Portland cement-based and may contain specific additives designed to react with the targeted COCs. Typical additives are bentonite, zeolites, flyash, cement kiln dust, and various silicates. Other types of grouts currently available are described below. Proportions of grout, water, and additives are determined through an optimization process depending on the site conditions, including type of soil, moisture content, and type and concentrations of contaminants.

Several in situ mixing techniques can be employed, based on specific site conditions, soil characteristics, and depth required. Mixing by crane-mounted augers, rakes, high-pressure jetting, low-pressure permeation, and simple mixing with a backhoe have all been employed. Most solidification/stabilization amendments are injected as slurries through drilling rods or other downhole tooling.

A treatability study would be needed to determine appropriate solidification/stabilization reagents to immobilize Sr-90 in the tank farm alluvial soil. Several reagents would be evaluated primarily on the basis of mixability, strength, and leaching of radionuclides from stabilized/solidified mixtures.

Implementability of this technology at CPP-31 would be constrained by the extensive subsurface infrastructure present and by the apparent preferential flow of the original liquid releases at these sites along infrastructure.

Several grout types and in situ mixing methods are described below.

3.2.2.4.2.8.1 Grout Types—

3.2.2.4.2.8.1.1 Portland Cement-Based Grouts—Portland cement-based grouts have been widely used at the INL Site and elsewhere to stabilize and/or solidify radionuclides in a wide range of media. The principal advantages of Portland cement grouting of waste zones include

- The uncured cement is a pumpable fluid that can fill voids and improve long-term stability of the site by reducing subsidence and providing structural support.

- Grouting the waste zone results in a low-permeability waste form with a high compressive strength that is resistant to leaching and weathering.

- The cement matrix provides a geochemically stable near-field environment for most radionuclides, including Sr-90, Cs-137, Pu, U, and many others. Sr-90 is strongly sorbed to cement matrices by exchange for Ca in some cement silicate hydrate and calcium aluminate sulphate hydrate phases. Cesium sorbs to concrete aggregate and forms cesium zeolites in cement matrices that limit solubility. Uranium solubility is reduced in strongly alkaline solution associated with Portland cement and decreases with age of the cements. Lanthanides and actinides are typically very insoluble in the strongly alkaline cement matrix.

Loomis et al. (1998) evaluated six grouts for bench-testing, including TECT HGTM (cementitious), U.S. Grout (cementitious-pozzlonic), GMENTTM- 12V (cementitious-pozzlonic), Enviro-Blend@ (phosphate based), WaxFix™ (molten paraffin based), and Saltstone (mostly pozzolonic). All of these grouts displayed the potential to be jet-groutable and potentially effective for reducing Sr-90 mobility in tank farm soil.

3.2.2.4.2.8.1.2 WaxFix—WaxFix is a paraffinic hydrocarbon, injected while hot and molten. Loomis et al. (1998) and Hanson et al. (2004) evaluated WaxFix for application to in situ grouting of SDA wastes. WaxFix can immobilize contaminants by coating and permeating waste material and by restricting the access of water to contaminants and waste. WaxFix can also provide structural support by eliminating voids and forming monoliths to prevent subsidence. WaxFix has several desirable characteristics for use at the INL Site that include the following:

- Low permeability to water, which reduces the likelihood of contaminant transport

- Substantial penetration into voids that may exist in the soil/waste matrix, enhancing long-term stabilization of waste

- Inert chemistry that is not likely to accelerate degradation

- Reduction of the generation of dust and particulates that could spread contamination, should waste retrieval eventually be desired.

WaxFix was used in 2004 for in situ grouting of beryllium reflector blocks and outer shim control cylinders buried in soil vaults and trenches at 15 separate locations at the INL Site SDA (ICP 2005). The objective was to reduce corrosion of the blocks and thereby reduce the release of contaminants from the blocks and transport to the groundwater.

3.2.2.4.2.8.2 Methods for Implementing In Situ Stabilization/Solidification—In situ solidification/stabilization is accomplished by mixing the solidification/stabilization reagent into the soil by some mechanical means, such as an excavator, tiller, auger, or injection/jetting technique. The most common device used for mixing solidification/stabilization reagent into relatively shallow soil is the excavator because it is widely available and is suitable for many applications; however, uniform mixing is difficult to achieve using conventional excavators, and they are limited by their reach. Tractor-mounted rotary tillers can achieve more uniform mixing than an excavator, but they are limited to applications at depths of 1.5 m (5 ft) or less.

For deep soil grouting, vertical augering and injection/jet grouting can provide uniform mixing or contact with the solidification/stabilization reagent and are less restricted by depth than most in situ solidification/stabilization reagent delivery techniques. Vertical augering involves drilling augers equipped with cutting and hollow mixing blades generally mounted on lattice boom track cranes. Vertical augering would be severely constrained by surface and subsurface infrastructure at the tank farm.

In situ grout injection uses an injection pipe, either drilled or hammered into the soil matrix, through which grout is injected under pressure into voids and pore space within the soil matrix. Once all of the voids are filled at a particular depth, the pipe is raised and more grout is injected. The injection process continues until the surface is reached. Grout injection has been conducted at depths of up to 50 m (Hayward Baker 2003).

Jet grouting has been used at the INL Site SDA in field trials for cementitious grouts and at full scale for WaxFix (Loomis et al. 2003, ICP 2005). Results of these field applications indicate that jet grouting is potentially effective in distributing grouts in disturbed soil, undisturbed soil, and waste zones. Successful application in areas with dense subsurface infrastructure like CPP-31 has not been demonstrated.

3.2.2.4.2.8.3 Summary—In situ solidification/stabilization is potentially effective and implementable at the tank farm after 2012 and will therefore be retained for further evaluation. Implementation would require bench-scale studies to determine a grout formulation and field trials of mixing systems.

3.2.2.4.2.9 Soil Flushing—In situ soil flushing would involve the injection of water and other reagents into the contaminated tank farm soil to solubilize Cs-137 and Sr-90. The resultant solution would be captured in an extraction well or interceptor trench and the liquid waste stream subsequently treated to remove the Sr-90 via ion exchange or another process. The following are considerations for in situ soil flushing (EPA 1996):

- Is most effective on soil with low silt or clay content
- Requires the drilling of injection and extraction wells onsite
- Requires greater understanding of the site’s geology than some other technologies.

The effectiveness of in situ soil flushing is limited by soil heterogeneity and by the ability to desorb contaminants from the soil matrix. Movement of the extraction fluid is difficult to control and monitor. For these reasons, the process option of in situ soil flushing is rejected and will not be further evaluated.

3.2.2.4.2.10 Electrokinetics—When direct current (DC) is applied to the soil volume, pore water and most contaminants move from the anode (the positive electrode) to the cathode (the negative electrode). Figure 3-8 shows graphically the prevailing theory as to what can occur within a soil pore in an electric field using electrokinetics (Alshawabkeh and Young 1999; Dzenitis 1997; Yeung, Hsu et al. 1997).

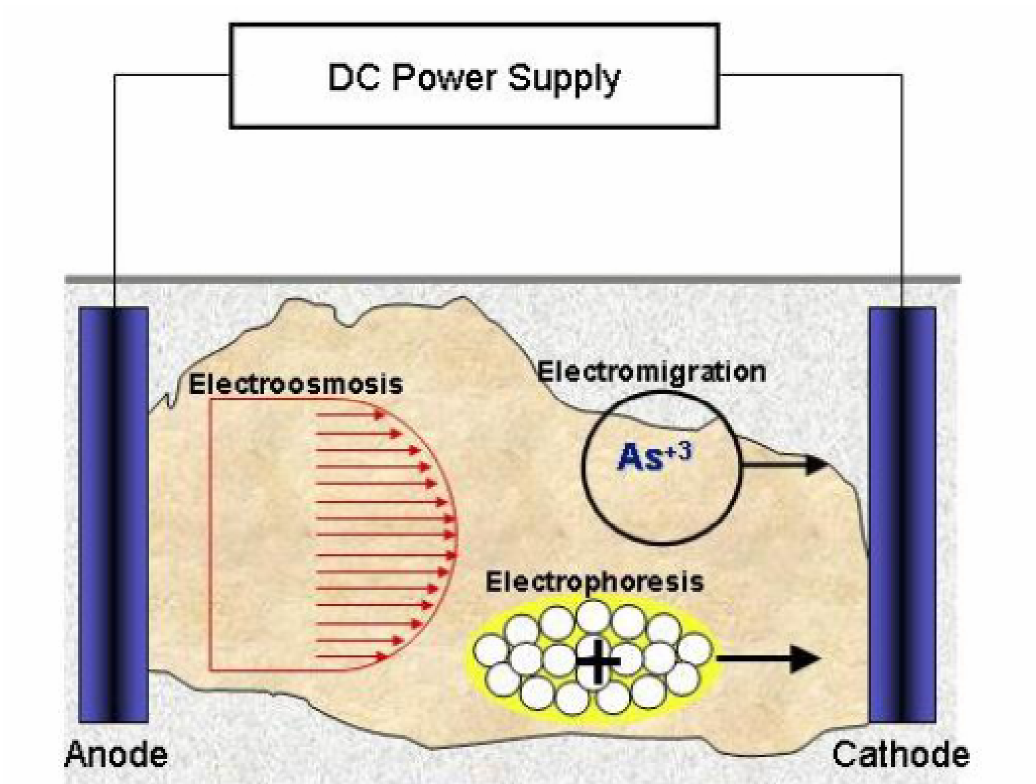

Figure 3-8. Conceptual view of electrokinetic processes within pore space of soil matrix.

Electrokinetics broadly includes the following five mechanisms:

- Electroosmosis[a] - movement of water under an electric field
- Electrophoresis - movement of particles under an electric field
- Streaming potential - electric field caused by the movement of water through a soil
- Sedimentation potential - electric field caused by particle movement through water
- Ion migration - movement of cations and anions under an electric field.

Soil typically has a negative surface charge. To balance this charge, a row of cations, such as sodium, calcium, and magnesium, line up along the soil particle surfaces. There may be other ions in the bulk pore water solution, but these are typically balanced. Common counter-anions in soil water are chloride, sulfate, and nitrate. Under the influence of a DC field, the rows of cations on the soil particle

a. Electroosmosis generally occurs in soils, and electrophoresis tends to occur in slurries and colloids. The boundary between the two processes is somewhat gradational but can be related to Atterberg limits.

surfaces start migrating towards the cathode by electrical attraction. The movement of this boundary layer of cations drags the bulk soil water with it. Within the bulk soil water, the individual cations also move towards the cathode and the anions move towards the anode. The movements of these individual ions are self-canceling and have no real effect on the bulk water transport. This ion movement, however, called electromigration, is very important when treating soil contaminated with metals, nitrates, sulfates, or other inorganic compounds.

Electrokinetic soil processing involves the insertion of anode and cathode electrodes into contaminated soil. A conditioning fluid is circulated at the electrodes, and an electric current is applied to produce an electric potential between the anode and cathode. Natural moisture or an externally supplied fluid serves as a conducting medium and a means to extract and exchange charged species that collect at the electrodes. This process is called electrophoresis, which is the mass flux of charged (ionic) particles under an electric field. Electrophoresis is at least an order of magnitude faster than transport of species by diffusion or electroosmotic advection.

During electrokinetic soil processing, some of the contaminant species are electrodeposited on the electrodes, whereas others are extracted through the use of chemical processes or ion-exchange systems within the process control container. The conditioning fluid is used to control or depolarize the cathode reaction to minimize premature precipitation of the incoming species. Conditioning fluids include acetic acid and chelating agents. Acetic acid depolarizes the reaction at the cathode and prevents base formation. The acetate anions migrate into the soil and solubilize contaminant species. Chelating agents are used to solubilize specific contaminants.

Electrokinetic soil processing can be used to treat soil for the removal of lead, cadmium, uranium, thorium, radium, and polar ionic species. Electrokinetic processing may effectively treat soil containing other contaminants (such as cesium); however, demonstrations have been limited. Electrokinetic processing for arsenic has been demonstrated for full-scale applications but not for radionuclides. Electrokinetic systems are suitable for Sr-90 according to some literature (Van Cauwenberghe 1997). Application of electrokinetic soil processing for treating radionuclides has been limited to bench-scale and pilot-scale testing. Although testing results have demonstrated varying degrees of success, this technology has not been demonstrated for full-scale applications on radionuclides.

The following are some of the factors that may limit the implementability and effectiveness of electrokinetic/electroosmosis for soil at the INTEC (Note: Many other parameters, taken together, make this a very difficult technology to implement):

- The effectiveness is sharply reduced for wastes with a moisture content of less than 10%.
- In unsaturated soil, the addition of water could potentially wash contaminants out of the area of influence.
- The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil.
- Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil. Electrodes made of inert materials such as carbon, graphite, or platinum should be used.
- Electrokinetics is most effective in clays because clay particles have a negative surface charge.
- The solubility and desorption potential of the contaminants may limit the success of the technology.

Due to the arid climate of the INL Site, a disadvantage of using an in situ electrokinetic process in the tank farm soil at the INTEC may be a lack of sufficient naturally occurring soil moisture. Addition of an externally supplied conditioning fluid may result in leaching of the contaminants (specifically the plutonium in the soil at the tank farm) from the soil and migration to the SRPA. In addition, other anion/cations, including metals and other radionuclides, will also transfer electrokinetically to varying degrees, possibly necessitating the use of ion exchange membranes or similar devices.

This technology will not be evaluated further based on lack of demonstrated effectiveness and implementability at sites similar to the tank farm.

3.2.2.4.3 Thermal—In situ thermal treatment of soil is the process of converting materials into glass or glass-like substances at high temperatures. Inorganic contaminants become immobilized in the glass matrix. The process option discussed here is in situ vitrification (ISV).

3.2.2.4.3.1 Vitrification—Vitrification is a thermal process that can be performed both in situ and ex situ. The ISV process involves heating contaminated media to extremely high temperatures then cooling them to form a solid mass. The ISV process uses an electric current to melt buried soil or other solid media, including containers, at extremely high temperatures (1,600 to 2,000^{o}C). Radionuclides and other contaminants are immobilized within the vitrified mass, a chemically stable, leach-resistant material similar to obsidian rock. An electrical distribution system, off-gas treatment system, and process control system are required for implementation. The off-gas system is required for emissions to ambient air during vitrification because some organic constituents and inorganic contaminants, such as H-3, Cs-137, and Sr-90, may be volatilized and released due to the high temperatures involved. A vacuum hood is often placed over the treated area to collect off-gases, which are treated before release. Vitrification reduces the volume, toxicity, and mobility of the contaminated materials but does not affect their radioactivity. Vitrified radionuclide-contaminated soil may require additional protective measures, such as shielding, to minimize radiation exposures. Because the treatment is entirely in situ, no off-Site activities are necessary to manage, treat, store, or dispose waste.

To employ ISV in areas with underground piping and utilities, an assessment would be needed to determine the effect of these underground structures on the melt process, e.g., shorting of current. Test Area North (TAN) investigated the use of ISV for the vitrification of underground tanks and surrounding soil, concluding this technology was viable. However, there were strong objections to its use based on many technical arguments.

In situ vitrification is a proven, commercially available technology that has been used to vitrify contaminated soil to a depth of about 7.6 m (25 ft).[b] Vitrification to deeper depths (about 12 m [40 ft]) has been achieved using a two-stage melting process. However, this process requires removal of a portion of the overburden soil while melting the lower portion of the soil column. The overburden soil is placed over the vitrified mass and vitrified as a second stage. Emerging research indicates that a single-stage melt to deeper depths may be possible in the near future.

The following are potential capabilities and limitations of ISV:

- Capabilities
  - Reduced leachability of immobilized inorganics and radionuclides

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b. Personal communication with Matt Haass, Geosafe, concerning GeoMelt technologies, June 1997.

- Long-term durability of the vitrified product that passes EPA's extraction procedure toxicity (EPTox), solid waste leaching procedure (SWLP), and toxicity characteristic leaching procedure (TCLP) leaching tests

- Can handle some buried objects, such as steel pipes and tanks

- Volume reduction

- Avoidance of excavation, processing, and disposal of soil, especially remote-handled materials, reduces potential exposures.

- Limitations

  - Waste composition and moisture content.

  - Presence of combustible materials.

  - Presence of process-limiting materials.

  - Volatilization of contaminants will require off-gas collection and treatment. Combustible gases may be produced. Radionuclides such as Cs-137, Sr-90, and H-3 may volatilize.

  - Potential shorting caused by buried utilities and engineered structures.

  - Depth limitations.

  - High cost of energy.

  - Highly trained operators required.

Although ISV is presently limited to treatment depths of 7.6 m (25 ft) or less using a single melt process, emerging research suggests that deeper treatment depths using staged or single melts may be attainable in the future. Because of the depth limitations and the difficulty in implementation, ISV is not retained as a process option.

3.2.2.5 Soil Removal. Residual Cs-137 and Sr-90 contamination in tank farm soil may be physically removed by excavation. Excavation is potentially effective and implementable at the tank farm after 2012.

Excavation to prevent exposures to future workers (RAO III) would require excavating to a maximum depth of 4 ft bgs in the tank farm and backfilling with clean soil. Excavation to remove Sr-90 contaminated soil from CPP-31 would require excavating the site to basalt and backfilling with clean soil. Excavation would not be implemented to prevent exposure of ecological receptors (RAO V).

The following factors affect the implementability of excavation technologies at the tank farm:

- Loading restrictions on the tank farm identified in TPR-7089. This procedure states that "Tank Farm load controls shall be established, implemented and maintained to ensure that any loads affecting the Tank Farm vaults do not increase the load on any structural member by more than 10% above the load from at-rest soil conditions." This requirement severely constrains use of large excavators in the tank farm. This criterion is assumed to be lifted after the tanks and vaults are grouted in 2011.

- Depth of excavation required and shoring requirements.

- Presence of subsurface infrastructure, including tanks and vaults, concrete valve boxes and pipe enclosures, piping, pipe supports, electrical supply, instrumentation, and cathodic protection. Some process liquid transfer lines and other utilities are planned to remain in service through 2035. Excavation would expose several tank vault walls, which will require an engineering analysis to determine if they will remain stable or if supports will be required to hold them in place.

- Soil and debris physical characteristics, including bulk density and hardness.

- Direct radiation exposures to workers. Conventional excavation techniques and equipment can generally be used in gamma exposure fields less than 200 mR/hr. Shielded or remotely operated equipment is typically required in high radiation fields greater than 200 mR/hr to ensure the safety of equipment operators.

- Production of fugitive dust and airborne contamination exposures to workers. Soil removal would require use of engineering and administrative controls to reduce risks due to fugitive dust emissions, worker exposures, and waste streams. Confinement of the action to as small an area as possible and containment of the excavation site in an enclosure lower these risks.

- Ongoing tank farm operations, including tank closures and D&D of surface structures. Excavation of most tank farm soil could be implemented in 2012 based on current planning schedules.

Several types of excavators that may be effective and implementable are discussed below. Due to the high direct radiation exposures that would be encountered during excavation at some tank farm locations, including CPP-31, excavators are discussed as either conventional or remotely operated.

3.2.2.5.1 Conventional Excavators—Conventional excavators include backhoes, trackhoes, front end loaders, wheel loaders, Bobcats, and others. Conventional excavators could be used to remove soil contaminated at relatively lower radiation levels, as well as removing overburden above soil contaminated at higher levels and laying back excavation side slopes in preparation for contaminated soil removal. Commercially available conventional excavation equipment can be fitted with lead exterior shielding and leaded or Lexan film glass to reduce direct gamma and beta exposures to the operator. Airborne exposures can be minimized using sealed operator cabins and inlet air filtration. Exposures can be further reduced by protective clothing, respirators or supplied air, and dust suppression techniques in the working area.

INTEC facility operations have used a vacuum excavation system called the Air Vacuum Excavation System (AVES) for several years to safely remove soil from areas that pose a risk to workers or near infrastructure where operating larger bucket excavators is difficult. The system uses a pressurized air lance to break up the soil, which is then removed through a vacuum and deposited in containers for disposal. The system can be operated from as far away as 300 ft from the excavation, which provides for reduced exposure to the worker. In addition, the vacuum operation mitigates the generation of fugitive dusts. The primary limitation of the AVES is the size of the particle that can be transported through the system (in general, objects in excess of 4 in. in diameter or having a single dimension greater than 5 in. may not pass through the system's vacuum line). This type of equipment is commercially available from several vendors.

Fugitive dust generation and airborne contamination generated during excavation can be controlled by spraying foams or other dust suppressants onto the digface and/or equipment operating area. Fugitive dust and airborne contamination can be contained using tent-type temporary sprung structures or more permanent Butler-type metal buildings. Both types are commercially available.

Conventional excavators and fugitive dust generation and airborne contamination controls are retained for further consideration for tank farm soil removal.

3.2.2.5.2 Remotely Controlled Excavators—Remotely controlled excavators and equipment can be used to reduce or eliminate exposure of the equipment operator to high radiation fields during soil removal. A control station and video cameras are typically used to control the excavator. Remotely controlled excavators provide the following advantages over conventional excavation equipment:

- Safety is increased by removing workers from potentially hazardous contamination sites during excavation.

- Operator efficiency is increased by providing a comfortable environment for the operator and eliminating the need for protective clothing, respirators, etc.

Most of the remotely operated excavators discussed in this section are adapted from conventional excavators. Sykes (2002) reviewed the status of remotely operated soil and waste retrieval technology for OU 7-13/14 at the INL Site. Full-scale remotely operated retrievals included Los Alamos Area P Material Disposal Area (MDA-P) and the Sandia Landfill. WESTON Solutions, Inc. used a computer-controlled, remotely operated 65,000-lb hydraulic excavator called HERMES to perform all initial excavation operations at MDA-P to mitigate detonation hazards. MDA-P operated from 1950 to 1984 and received materials from the burning of high explosives (HE), HE-contaminated equipment and material, barium nitrate, construction debris, trash, vehicles, empty drums, and miscellaneous containers. Thirty-one thousand cubic yards of explosives-contaminated soil, including 607 tons of steel, were remotely excavated over a period of 23 months.

A remote robotic manipulation and excavation system was used for characterization and retrieval of buried chemicals, explosives, and radioactive materials at Sandia National Laboratory’s Technical Area Two (TA-II) (Weston 2005). This robotic system allowed for use of a conventional excavator for most operations, such as removal of overburden and rubble in the landfills, while employing the versatility and dexterity of the robotic manipulator to address any sensitive objects once they had been uncovered, without placing personnel in direct contact with the hazard.

Valentich (1993) evaluated the effectiveness of conventional construction equipment to retrieve buried TRU wastes. The Caterpillar 325L excavator (Figure 3-9) was found to be an effective tool for retrieving buried waste. This tracked excavator can be fitted with excavation buckets with capacities of less than 1 yd^3 to over 7 yd^3, as well as other attachments, including shears and pulverizer jaws (Figures 3-10 and 3-11). The shears are used for demolishing steel structures and preparing bulk scrap for further processing. The pulverizer jaws can pulverize concrete, cut rebar, and separate rebar from concrete. The estimated cost to modify this unit for remote operation was estimated at $1M in 1993 (Valentich 1993).

Figure 3-9. Caterpillar 325L fitted with excavation bucket.

Figure 3-10. Caterpillar 325L fitted with 360-degree rotation shears.

Figure 3-11. Caterpillar 325L primary pulverizer jaws.

A remotely operated military version of the Caterpillar 325L, called the Automated Ordnance Excavator (AOE) (Figure 3-12) is currently in use by the Army Corps of Engineers (Global Security 2005). The long-reach AOE is designed to maximize the distance between the bucket and machine and can reach 60 ft and dig to 48 ft bgs.

DOE at the Oak Ridge National Laboratory (ORNL) developed the Remote Excavation System (RES), a Mercedes-Benz Unimog truck modified with a Case 580E commercial backhoe attachment for teleoperation and demonstrated the system at the INL Site (Valentich 1993). The teleoperation technology was designed to be transferable to a variety of vehicles and mechanical extensions for application to specific sites.

The modifications to the vehicle for remote operation included modifying the hydraulic systems for computer control (Figure 3-13). High-performance servovalve components were used to improve the dexterity over the existing manual valves. Hydraulic pressure sensors provide indications of force exerted by the backhoe. The backhoe and front-end loader were outfitted with position encoders, and remote viewing is provided by two color television cameras with pan and tilt mechanisms mounted on the truck body and a camera mounted on the backhoe boom. The RES was demonstrated at the INL Site to excavate soil at rates only slightly below those achieved by operating the excavator manually and was proven to be reliable and easy to operate.

The Brokk (Figure 3-14) is a commercially available remotely operated wheeled or tracked demolition machine, available in several sizes. The vehicle can be controlled by wire or wireless radio remote control by one person, up to 400 ft away from the demolition activities. The Brokk can be used to remove or demolish infrastructure, including tanks, piping, concrete vaults, and others, using a variety of end effectors. The INL owns a Brokk 250 and end effectors including a scabbler, shear, grapple, bucket, and hammer.

Figure 3-12. AOE excavator.

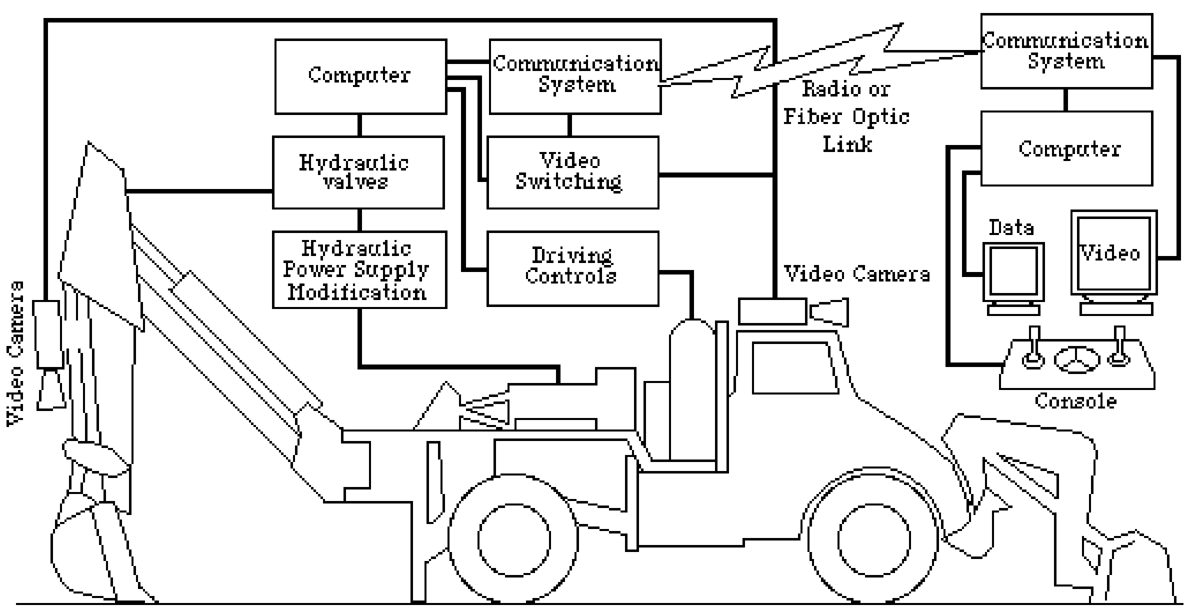

Figure 3-13. Schematic of RES.

Figure 3-14. Brokk 180.

Sykes (2002) determined that the following conditions decrease the production rate of retrievals:

1. Using remote technologies
2. Using one piece of equipment to dig, size, and sort
3. Unexpected conditions.

The following conditions were determined to increase the production rate of retrievals:

1. Larger bucket sizes
2. End-effectors readily available for changing operations
3. More than one retrieval operation in progress
4. Second piece of equipment for sizing and sorting.

Remote excavators in combination with conventional systems may effectively remove the contaminated soil, abandoned infrastructure, and debris at the tank farm. Remotely operated excavators like the Caterpillar 325L are commercially available (Weston 2005). Therefore, removal by remote systems will be retained for further evaluation.

3.2.2.5.3 Vacuum Excavators—INTEC facility operations have used a vacuum excavation system called the AVES for several years to safely remove soil from areas that pose a risk to workers or near infrastructure where operating larger bucket excavators is difficult. The system uses a pressurized air lance to break up the soil, which is then removed through a vacuum and deposited in containers for disposal. The system can be operated from as far away as 300 ft from the excavation, which provides for reduced exposure to the worker. In addition, the vacuum operation mitigates the generation of fugitive dusts. The primary limitation of the AVES is the size of the particle that can be transported through the system (in general, objects in excess of 4 in. in diameter or having a single dimension greater than 5 in. may not pass through the system's vacuum line). This type of equipment is commercially available from several vendors. Vacuum extraction systems will be retained for further evaluation.

3.2.2.6 Disposal. Disposal would be used in combination with removal to meet RAOs by isolating contaminated soil in an engineered repository, thereby breaking contaminant migration and exposure pathways. All excavated soil and debris would be disposed of in the ICDF, which is assumed to be available for the duration of soil removal. Disposal containers and transportation would be provided by the ICDF operating contractor. Compliance with any applicable Department of Transportation requirements for the haul route from INTEC to ICDF is assumed to not increase scope, complexity, or cost of disposal.

3.2.3 Summary of Retained Remedial Technologies for Tank Farm Soil

Table 3-1 summarizes retained technologies for tank farm soil. The GRAs of ICs, monitoring, containment, in situ treatment, removal, and disposal were identified for INTEC tank farm soil. Three remedial technologies were identified for the GRA of ICs, including administrative controls, access restrictions, and property transfer controls. All three process options were retained for further consideration.

Monitoring options, including soil sampling and radiochemical analysis and in situ gamma monitoring, were retained for further consideration.

Containment process options identified included RCRA Subtitle C, evapotranspiration, rock armor, Hanford barrier, concrete, asphalt, MatCon asphalt, and flexible membrane capping systems; and surface water management techniques including maintaining the TFIA. All capping systems were retained for further consideration. Subsurface barriers were screened out at the technology level as not effective or implementable.

In situ microbial bioremediation process options were rejected because none have been successfully demonstrated to be able to effectively remove or immobilize Cs-137 and Sr-90 under conditions similar to those found at the INTEC. Phytoremediation was retained because it has been demonstrated to be capable of reducing soil concentrations of Cs-137 and Sr-90.

Four of the physicochemical in situ treatment options were retained: liquid atomized apatite injection, carbon dioxide gas injection, soil vapor extraction, and solidification/stabilization. Soil flushing was rejected because of the difficulty in controlling introduced solutions in heterogeneous soil and the potential to induce leaching and transport of soil contaminants to groundwater. Electrokinetics was rejected because it has not been demonstrated for full-scale use with radionuclides. The thermal in situ vitrification was rejected because of low technical implementability at the tank farm.

Conventional and remotely controlled excavators and vacuum excavators were identified as removal process options. For the GRA of disposal, ICDF was the only process option identified.

3.2.4 Description of Remedial Technologies for Groundwater

Table 3-2 summarizes the initial identification and screening of remedial technologies for SRPA groundwater. Each of the technology process options is discussed in detail below

3.2.4.1 Institutional Controls. ICs are discussed in Section 3.2.2.1 for both OU 3-14 soil and groundwater. ICs potentially applicable to the SRPA are listed in Table 3-2.

3.2.4.2 Monitoring. DOE-ID (2002) defines the approach for monitoring effectiveness of the OU 3-13 Group 5 remedy. Group 5 is defined as the SRPA contaminated by Sr-90, I-129, and H-3 released from INTEC sources. As noted in Section 1, the OU 3-13 remedy was an interim action, and OU 3-14 is tasked with the final remedy for the SRPA contaminated by INTEC releases.

DOE-ID (2002) contains two components, a plume evaluation Field Sampling Plan and a Long-Term Monitoring Plan. The plume evaluation Field Sampling Plan was developed to determine if contingent pump and treat remediation of the SRPA is necessary. The Long-Term Monitoring Plan was developed for long-term monitoring of the INTEC groundwater plume outside of the INTEC fence and to monitor the flux of contamination in the SRPA migrating from beneath INTEC.

The scope of OU 3-14 SRPA final remedy monitoring is assumed to be contained within the OU 3-13, Group 5, scope as described in DOE-ID (2002); therefore, no new monitoring components are required. Any changes to the Group 5 monitoring approach would be defined during the OU 3-14 RD.

3.2.4.3 Containment. Containment technologies interrupt the exposure pathways to contaminated groundwater and prevent or reduce transport of contaminants into the surrounding environment. While containment reduces the mobility of the contaminants, it does not reduce their toxicity or volume. Groundwater modeling results reported in the OU 3-14 BRA (DOE-ID 2006) indicate that Sr-90 groundwater concentrations above allowable levels will not extend beyond the INTEC fenceline after 2095. Groundwater containment is therefore not considered effective in meeting RAOs but is included for completeness. Containment technology types include groundwater controls (hydraulic barriers) and horizontal or vertical barriers. Each of these is discussed below.

3.2.4.3.1 Groundwater Controls—This containment method uses extraction and/or injection wells or interceptor and/or recharge trenches to create an artificial hydraulic barrier. These artificial hydraulic barriers limit the migration of contaminated groundwater by changing the local hydraulic gradients.

3.2.4.3.1.1 Interceptor/Recharge Trenches—Interceptor/recharge trenches include any type of trench or buried conduit to extract or recharge groundwater by gravity flow. Interceptor/recharge trenches function essentially as an infinite line of extraction/injection wells. The trenches may be excavated to a depth of approximately 9 m (30 ft) using conventional excavators and to much greater depths using telescopic excavators, draglines, or clamshells. After excavation, a perforated pipe is placed in the trench and backfilled with clean gravel. If surface water collection is desired, the gravel will be open at the surface; if not, the last few feet of the trench will be filled with soil and revegetated. Collected water will drain by gravity to a pump station where it will be extracted. Recharge water is placed in the trench to drain to the subsurface by gravity. This process is also known as interceptor trenches and subsurface drains. Synthetic membrane cutoff walls may also be included in this category and are discussed below under vertical barriers.

The depth of the SRPA and the formation material, fractured basalt, makes use of interceptor/recharge trenches impractical. Interceptor/recharge trenches will not be evaluated further.

Table 3-2. Preliminary screening of technologies and process options for the Snake River Plain Aquifer. Technologies shown with shading are eliminated based on effectiveness and implementability.

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
Institutional controls	Administrative controls	CFLUP.	Tracks and reports activities that could occur on INL CERCLA sites with ICs.	
		Public notices.	Notify stakeholders of changes in ICs.	
		DOE directives.	Legally binding on DOE and contractors; can include well-drilling restrictions or easements for monitoring, restrictive covenants, or land withdrawal documentation.	
		NEPA.	Requires that all federal actions subject to NEPA receive appropriate evaluation.	
		Work controls.	Includes specific regulatory requirements for work activities, including well drilling and sampling. Addresses environmental management, radiological controls, safety and industrial hygiene, and training requirements.	
		Notice of soil disturbance (NSD).	Required for planned disturbance, including well drilling.	
	Access restrictions	Visible restrictions.	Barriers, permanent markers, or warning signs.	
		Access controls.	INL Site access controls under the authority given in 42 USC 2278a as implemented by 10 CFR 860, “Trespassing on Department of Energy Property.” Security forces and other administrative controls.	
		Locked and labeled wells (pre-2095).	Physical barriers to prevent access to existing or planned site monitoring, injection, or extraction wells.	

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
Monitoring	Property transfer controls	Deed or regulatory restrictions.	Statutes require that DOE indicate in property transfer deeds the presence of contamination and any restrictions on use of the property due to such contamination.	
Containment	Groundwater controls	Interceptor and/or recharge trenches.	Hydraulic control of contaminated groundwater using interceptor and/or recharge trenches.	Not applicable. Depth to water is too great for trenches to be implemented.
		Extraction and/or injection wells.	Hydraulic control of contaminated groundwater using extraction and/or injection wells.	Potentially effective and feasible.
	Horizontal and vertical barriers	Slurry walls. Membrane cutoff walls. Sheet pilings. Grout curtains. Grout injection. Cryogenic barriers.	Various types of barriers to contain contaminated groundwater	Not effective, not technically implementable due to depth to groundwater, transmissivity of SRPA, fractured rock matrix.
In situ treatment	Biological	Bioremediation.	Stimulation of indigenous microorganisms to degrade contaminants.	Not applicable. Not demonstrated for the COCs at the INTEC. Transmissivity of the SRPA and lack of a defined source zone limit implementability and effectiveness of in situ treatment options.
	Physicochemical	Hydrofracturing.	Water and/or slurried sand is forced under high pressure into the contaminated zone to create or enhance groundwater flow pathways.	Not applicable. Due to depth to water and inability to confirm effectiveness, this process option is not practical.
		Oxidation/reduction.	Injection of chemicals into contaminated groundwater to oxidize or reduce and precipitate radionuclides.	Not applicable. Due to depth to water and lack of demonstrated effectiveness, this process option is not practical.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		Passive treatment wall.	Construction of in situ treatment wall to degrade, sorb, exchange, or precipitate radionuclides in contaminated groundwater.	Not applicable. Due to depth to water and inability to confirm effectiveness, this process option is not practical. Transmissivity of the SRPA and lack of a defined source zone limit implementability and effectiveness of in situ treatment options.
		Electrokinetics.	Contaminant transport toward extraction well is accelerated with the use of direct current applied to electrodes placed in the contaminant plume.	Not applicable. Due to depth to water and inability to confirm effectiveness, this process option is not practical. Transmissivity of the SRPA and lack of a defined source zone limit implementability and effectiveness of in situ treatment options.
		Solidification/ stabilization.	Aquifer materials are mixed with cementitious materials to form a solidified matrix.	Not applicable. Due to depth to water and inability to confirm effectiveness, this process option is not practical. Transmissivity of the SRPA and lack of a defined source zone limit implementability and effectiveness of in situ treatment options.
Removal	Groundwater extraction	Extraction wells.	Wells used to extract groundwater.	Potentially applicable and implementable.
Ex situ treatment	Physicochemical	Ion exchange (general).	Water treated via packed columns of general, nonspecific ion exchange resins to remove most contaminants.	Potentially applicable. Can remove radionuclides to acceptable levels. Depleted resins will require further treatment or disposal. May require regeneration.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		Ion exchange (specific).	Water treated via packed columns of specialty, specific ion exchange resins to selectively remove contaminants.	Potentially applicable. Resins are available specific to Sr at various stages of development. Low concentrations of Sr may limit effectiveness. Can remove radionuclides to acceptable levels. Depleted resins will require further treatment or disposal. May require regeneration.
		Electrodialysis.	Separation of ionic species from water by applying a direct current electrical field and using ion-selective membranes.	Not applicable. While there is some specificity, i.e., monovalent from multivalent, there are large concentrations of monovalent anions, e.g., HCO_3^-. There are similar technical issues with general ion exchange plus the fact that generally clean water is needed for the feed. May be applicable for a secondary process but not a primary.
		Electrodeionization.	Electrodeionization is a continuous, chemical-free process of removing ionized from the feed water using DC power. The electrodeionization module uses a spiral wound membrane and ion exchange resins in a pressure vessel.	Not applicable. Similar rationale to general ion exchange and electrodialysis. Also, neither this or electrodialysis has been demonstrated to meet the MCLs for the COCs.
		Reverse osmosis.	Reverse osmosis (RO) uses a selectively permeable membrane under high pressure that allows water to pass through it but traps heavy metals and radionuclide ions on the other side of the membrane. If used for removing radionuclides from water, the size and charge of the ion being treated affect RO.	Potentially applicable. Need to determine an acceptable ratio of clean water to reject water. Requires pH adjustment to minimize scaling. This could also serve as a pretreatment or posttreatment for another option.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		Electrolytic oxidation/reduction.	This uses DC electricity set at specific voltage and current to selectively remove the ionic contaminates.	Not applicable. While potentially applicable in theory and some limited laboratory work, this technology is difficult to implement based on size of operations and low concentration.
		Chemical oxidation/reduction.	Addition of oxidation or reduction agents to extracted groundwater to alter contaminant's valence and promote separation and/or precipitation.	Not applicable, no demonstrated effectiveness for Sr-90 removal.
		Chemical precipitation.	Chemical coagulants and flocculants are added to extracted groundwater to precipitate contaminants. Usually accompanied with pH adjustment.	Not considered applicable While Sr precipitation is well-known (chemistry similar to Ca), it is not selective. Therefore, this would of necessity precipitate a large amount of groundwater constituents for a small amount of Sr and is not practical.
		Freeze crystallization.	Salt solutions can be separated into pure ice and pure salt by eutectic freeze crystallization. Eutectic conditions are defined by the point of intersection of the ice line and solubility line of salt solution. By operating a crystallizer at eutectic conditions, ice and salt can be produced simultaneously. A direct gravitational separation of ice and salt is achieved based on the large differences between salt and ice densities.	Not applicable. Not demonstrated to meet MCLs for strontium.
		Adsorption.	Removal of contaminants by adsorption onto the surface of an activated alumina media.	Not applicable. Not demonstrated to meet MCLs for strontium.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		Introduction of chelation agents to form ligands that enhance contaminant mobility during extraction. This process is primarily useful as a pretreatment, i.e., for filtration.	Not applicable as a standalone treatment. Applicable as a pretreatment.	Introduction of chelation agents to form ligands that enhance contaminant mobility during extraction. This process is primarily useful as a pretreatment, i.e., for filtration.
		Solvent extraction.	The groundwater would be treated via a system of solvent extraction columns to extract Sr-90. This requires a back-stripping column and a method to remove them from the raffinate as well as organic cleanup and recovery.	Not applicable. While the COCs are extractable (Oh 2001), the concentrations are too low and it will not be effective.[a] Based on the size of the system, the low concentrations, and technical difficulties, this technology is considered not applicable.
	Physical	Filtration (nanofiltration, ultrafiltration, and microfiltration).	Filtration is the physical process whereby particles suspended in water are separated by forcing the fluid through a porous medium (i.e., a filter). The suspended particles are trapped in the filter. Filtration relies on the pore size of the membrane, which can be varied to remove particles and molecules of various sizes.	Potentially applicable as a pretreatment option. For a given pressure, has a larger ratio of clean water to reject water than RO. Needs to have pretreatment to remove COCs from clean water. May serve as a pretreatment for another option to remove total suspended solids.
		PEW evaporator system.	Pipe or transport extracted groundwater to the existing PEW evaporator system for treatment along with other INTEC wastewaters. Treatment process consists of the evaporation of contaminated liquids followed by management of residuals.	Not applicable. Residual material, such as sludge, will require further treatment or disposal. Will reduce the volume of material for further treatment or disposal. The volume of water potentially requiring evaporation may make this process impracticable. The groundwater chloride exceeds the PEW WAC.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		New evaporation ponds.	Construct a lined evaporation pond and pump the extracted groundwater (pretreatment or posttreatment) to the pond for passive solar evaporation.	Potentially applicable. Residual material, such as sludge, will require further treatment or disposal. Will reduce the volume of material for further treatment or disposal. The volume of water potentially requiring evaporation may make this process impracticable if used as a primary process. May be risk for COC transfer to air from winds.
		Evaporation - Existing ICDF evaporation pond	Use existing ICDF evaporation pond for treatment and disposal of sidestreams.	Not applicable, pond would not be available when required based on current closure schedule for ICDF.
		New evaporator or distillation column.	Pipe or transport extracted groundwater to a new evaporator (or distillation column) for treatment. Treatment process consists of the evaporation of contaminated liquids followed by management of residuals.	Potentially applicable. Residual material, such as sludge, will require further treatment or disposal. Will reduce the volume of material for further treatment or disposal. The volume of water potentially requiring evaporation may make this process impracticable if used as a primary process.
	Thermal	Thermal.	High-temperature treatment of contaminants and/or matrix.	Not applicable. Process option not suitable for metals in water (Freeman 1989).
	Biological	Algal cells in silica gel.	A biosorption process for removing radionuclides and/or metal ions from water based on their strong affinity of biological materials. Contaminated water is passed through a silica gel matrix containing algal cells.	Not applicable. Process option not demonstrated for use on radionuclide contaminants.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		Fixed bacterial film.	A sorption process for removing radionuclides and/or metal ions from water based on their strong affinity of biological materials. Contaminated water is passed over a fixed film of bacteria. The bacteria accumulate the metals or radionuclides.	Not applicable. Process option not demonstrated for use on radionuclide contaminants.
		Wetlands-based treatment.	Constructed wetlands use natural geochemical and biological processes to accumulate and remove metals and radionuclides from influent groundwater.	Not applicable. Process option not demonstrated for use on radionuclide contaminants.
		Phytoremediation.	This system flows the water through lagoons containing plants and vegetation that uptake the COCs. The plants are removed and disposed as low-level radioactive waste.	Not applicable. Process option not demonstrated for use on radionuclide contaminants ex situ.
Disposal	Disposal	Existing INTEC percolation ponds.	Send treated groundwater to existing INTEC percolation ponds via service waste transfer lines.	Potentially applicable.
		Discharge to INTEC Sewage Treatment Plant (STP).	Conveyance to INTEC STP for disposal and treatment.	Not applicable. The INTEC STP cannot treat for radionuclides.
		Re-injection wells.	Treated groundwater that meets MCLs and RAOs can be injected into the SRPA via injection wells. Treated groundwater with contaminants above MCLs may potentially be reinjected into the groundwater contaminant plume by invoking a statutory waiver under CERCLA section 121(d). However, the final remedial action will be required to meet the MCLs in the aquifer.	Potentially applicable. Can only dispose treated groundwater.

Table 3-2. (continued).

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
		ICDF evaporation pond.	Send process condensates to existing evaporation pond.	Not applicable, pond will likely not be available when required.
	Storage	Storage tanks, drum storage.	Process options for temporary storage of untreated groundwater.	Potentially applicable. For temporary storage only, prior to treatment. Not applicable as a permanent solution.

a. Todd, Terry A., Battelle Energy Alliance, personal communication to Samuel C. Ashworth, Battelle Energy Alliance, March 16, 2005.

3.2.4.3.1.2 Extraction Wells—Movement of contaminated groundwater can be controlled by extracting sufficient water from pumping wells to create drawdown of the water table, resulting in a cone of depression that induces flow to the extraction well. Downgradient migration of contaminants can be intercepted by one or more extraction wells, thereby providing hydraulic containment of the plume.

3.2.4.3.2 Vertical Barriers—Vertical containment technologies include subsurface barriers, such as slurry walls, synthetic membrane cutoff walls, sheet piling, and grout curtains. These barriers restrict horizontal migration of the groundwater. None of these technologies are effective or feasible due to the large area of the dissolved phase Sr-90 plume, the depth to groundwater, the high transmissivity of the SRPA and the fractured rock matrix. Vertical groundwater barriers are therefore not considered further in this FS.

3.2.4.3.3 Horizontal Barriers—Horizontal barriers to limit contaminant flux from tank farm soil to the SRPA were discussed previously. Horizontal barriers are not otherwise applicable to the SRPA and are not considered further.

3.2.4.4 In Situ Treatment. In situ treatment involves subsurface treatment of groundwater within an aquifer, without pumping water to the surface. In situ treatment methods can include both passive and active treatment technologies. An example of passive in situ treatment would be a permeable reactive barrier to immobilize contaminants or transform them into less toxic forms. An example of an active in situ technology would be air sparging to stimulate biodegradation of organic compounds in groundwater. Other examples of in situ treatment technologies include electrokinetic remediation, chemical oxidation/reduction, and contaminant sequestration by induced precipitation of minerals within an aquifer.

At sites with relatively shallow depths to groundwater (<50 ft), excavation of trenches or infiltration galleries are often the most effective means of intercepting groundwater flow. So-called funnel-and-gate treatment systems use impermeable slurry walls or sheet pilings to funnel the flowing groundwater to a treatment zone, such as a permeable reactive barrier. At sites where the groundwater is too deep for excavation of trenches, injection wells have been employed to introduce air or chemicals into the aquifer to transform or immobilize contaminants. Such systems require well spacings close enough to preclude flow of untreated groundwater between adjacent treatment wells. The technical feasibility of in situ treatment using injection wells depends on several factors, including the depth to groundwater and whether the site is underlain by rock or unconsolidated sediments. Well installation costs are much higher for deep wells installed in hard rock, as compared with shallow wells installed in basin-fill alluvium.

The depth to groundwater beneath INTEC is approximately 470 ft below surface, which includes approximately 40 ft of unconsolidated surficial alluvium and the remainder primarily basaltic lava. The SRPA is among the nation's most productive aquifers and consists of a thick sequence of quaternary basalt flows, some of which are separated by thin sedimentary interbeds deposited at the land surface during the intervening periods between volcanic eruptions. Groundwater flow in the SRPA occurs predominantly through fractures (joints) in the basalt and along rubble zones at flow contacts (bedding planes). In the eastern SRPA, regional groundwater flow is to the southwest. Hydraulic conductivities in the SRPA near INTEC commonly exceed 1,000 ft/day (0.35 cm/s). Hydraulic conductivities beneath INTEC are among the highest anywhere in the INL Site. The very large hydraulic conductivities and fractured nature of the basalt aquifer matrix result in very rapid groundwater flow velocities of approximately 5 ft/day at INTEC.

In situ treatment of trichloroethelene (TCE) is currently implemented at the TAN TSF-05 injection well under the ROD Amendment for OU 1-07B (DOE-ID 2001). The residual source of TCE exists as a dense nonaqueous-phase liquid entrained in sludge injected into the well and trapped in fractures and pore space in the formation, extending about 50 ft radially from the well. Bioremediation using anaerobic reductive dechlorination converts TCE to carbon dioxide and water, using injected sodium lactate or whey as an electron donor. Both sodium lactate and whey also act to reduce the interfacial tension between the TCE and the solid phases, resulting in increased bioavailability.

However, physical features of OU 1-07B that allow for in situ treatment of the aquifer are lacking at OU 3-14. At OU 1-07B, a residual source exists at a precisely known, relatively small location in the aquifer. Amendments can be injected through the TSF-05 injection well, which is also the source of the contamination. At OU 3-14, the residual contaminant sources that are predicted to pose an unacceptable risk to the SRPA post-2095 are located in the vadose zone and perched water, not in the aquifer. Contaminants are predicted to migrate into the SRPA over a large area, resulting in a diffuse, areally extensive plume. Therefore, no residual source area exists in the aquifer to target using in situ treatment. In situ treatment of dissolved-phase metals or radionuclides over large areas in aquifers as deep and as transmissive as the SRPA has not been successfully demonstrated.

Table 3-3 lists the potential technologies that were considered for in situ treatment of SRPA groundwater. All of the in situ treatment methods were deemed impractical or technically infeasible due to the great depth to the SRPA and the rapid flow velocities of groundwater within the aquifer. Excavation of trenches is obviously not possible, and the number of deep treatment wells that would be required to intercept groundwater flow would be cost-prohibitive. Therefore, though in situ methods might be feasible for the contaminated alluvium and/or perched water, in situ technologies will not be considered further for treatment of SRPA groundwater contaminated by INTEC releases.

3.2.4.5 Removal.

3.2.4.5.1 Extraction Wells—Groundwater pumping at relatively high rates may potentially remove sufficient pore volumes of water to increase the concentration gradient and thereby the driving force for desorption of Sr-90 from aquifer solids into the water. To be effective, pumping would continue until the Sr-90 entering from the vadose zone was depleted and most of the sorbed Sr-90 in the SRPA was removed or decayed, resulting in no rebound in Sr-90 concentrations after pumping ceased.

The number of wells, well placement, and pumping rates required to reduce Sr-90 aquifer concentrations below the MCL everywhere in the aquifer by the year 2095 were simulated using the OU 3-14 BRA base case TETRAD SRPA model. The cleanup area included residual Sr-90 contamination from the former CPP-03 injection well in the southern INTEC. The detailed results of modeling are provided in Appendix A and are summarized below.

Remediation was simulated using two pumping periods and three wells, to account for the multiple sources. To determine well locations, the location of the peak aquifer concentration through time was determined. This location varies with plume location in the horizontal plain and required three well locations. For simplicity, all three wells were assumed to be completed between the water table and the top of the HI interbed. Pumping rates for the wells were all equal but different pumping rates were applied to an early and late pumping period. The rate was determined such that concentrations in the aquifer are reduced below 8 pCi/L beyond year 2095. These rates and locations were chosen through manual iteration and do not represent a mathematically optimal solution.

The three well locations are illustrated in Figure 3-15. In order to reduce the Sr-90 concentrations below 8 pCi/L, it will require initially pumping these three wells at a combined production rate of 550 gpm. Produced concentrations are quite low given that the aquifer concentrations are just above the MCL in that region of the aquifer during the 2077-2102 time period. Later in time, the two northern wells can capture Sr-90 arriving from the vadose zone with these wells pumping at a lower rate. They are pumped during the 2102-2123 time period at a combined rate of 183 gpm. Pumping the northern wells longer than year 2095 is required because simulated concentrations arriving in the aquifer from the tank farm continue beyond year 2095. This longer time period is also required to remove several pore volumes in order to counter adsorption processes in the aquifer.

All extracted water was routed to an injection well, and the effects of reinjection were accounted for in the simulations. Complete simulation results including Sr-90 distribution in the aquifer over time are provided in Appendix A. The use of extraction wells as a groundwater control process option will be retained for further consideration.

3.2.4.6 Ex Situ Treatment. Groundwater extracted from the SRPA for containment or cleanup would require ex situ treatment for removal of Sr-90 to drinking water standards, prior to disposal. This section describes ex situ treatment process options for Sr-90.

3.2.4.6.1 Physicochemical—Physicochemical treatment applies physical chemistry processes to separate contaminants from their carrier medium, using technologies such as distillation, adsorption, and filtration. Physicochemical treatment may be implemented as a stand-alone process or as part of a treatment train.

Limitations of physicochemical treatment may include inhibition of the treatment process reaction by impurities in the groundwater and the potential generation of hazardous byproducts.

3.2.4.6.1.1 Ion Exchange—Ion exchangers are insoluble solid materials that carry exchangeable cations or anion. These ions can be exchanged for a stoichiometrically equivalent of other ions of the same sign when the ion exchanger is in contact with an electrolyte solution (Helfferich 1995). Ion exchange involves pumping contaminated groundwater (after extraction) through vessels containing beds of ion-exchange media. Ion exchange removes contaminants from groundwater by exchanging the contaminate ionic species with innocuous ions (e.g., hydroxide, chloride, sodium) present in the resin. This exchange results in the concentration of the contaminant ions on the ion-exchange resin. There are many different ion exchange resins, both organic and inorganic, for general and specific usage. The results of the screening suggest that ion-specific resins might be used for this application.

Many resins have been evaluated for effectiveness (i.e., equilibrium partition coefficient or K_d). More than 30 resins had K_d values for Sr ranging from 1,000-10,000 mL/g, when tested using Hanford neutralized wastes (Svitra, Marsh, and Bowen 1994). Hanford is currently using a specialty zeolite (clinoptilolite) for removing Sr from groundwater, and Cs and Sr have recently been removed from a TAN basin using chabazite (a zeolite) that is effective for Na plus Ca less than about 200 ppm. The INTEC groundwater averages less than 100 ppm. These resins are fairly selective for Sr depending on the background chemistry (e.g., Na and Ca).

Depleted resins (or resins that have reached their adsorptive capacity for the targeted ion) may be disposed or regenerated with chemical reagents and returned to service with fresh ion-exchange sites.

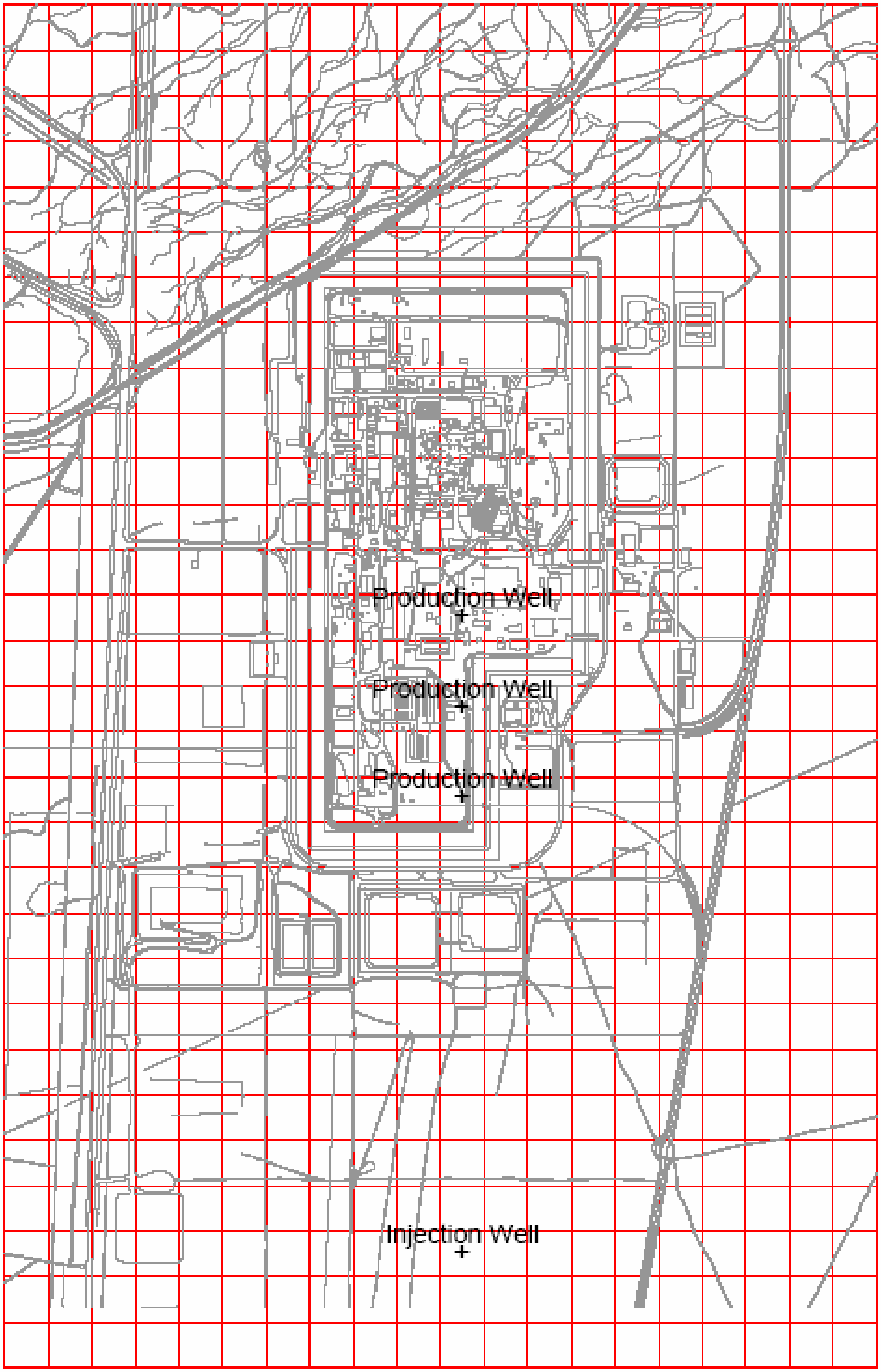

Figure 3-15. Pump and treat for complete remediation well locations.

The following factors may limit the implementability and effectiveness of ion exchange:

- Competing ions.
- Low concentrations of COCs.
- Regeneration will result in secondary wastes requiring treatment (such as evaporation and/or neutralization).

Ion exchange may be an effective treatment option, but additional testing may be required to determine whether Sr can be reduced to levels that will allow the disposal of the treated groundwater. Treatability tests of ion-exchange resins to treat the groundwater at the INTEC, in addition to ongoing programs, may be necessary.

3.2.4.6.1.2 Electrodialysis—Electrodialysis consists of separation of ionic species from water by applying a direct-current electrical field. The ion-selective membranes used in electrodialysis (cation- and anion-exchange membranes) selectively permit the passage of cations and anions. By alternating the cation- and anion-exchange membrane between two electrodes, alternate dilute and concentrated cells are created. This results in the separation of the ionic species from water.

The heart of the process is the electrodialysis stack consisting of alternating anion and cation exchange membranes separated by spacers. There are several circuits in the stack, such as feed (diluate) and brine (concentrate), due to channels formed by manifolds in membranes and spacers. The spacers direct the feed and brine solutions into the corresponding chambers and promote flow distribution. A set of two membranes and two spacers forms a cell or cell pair and hundreds of cells can be installed in one stack. The driving force is a direct current between anodes (positive electrodes) and cathodes housed at the two ends of the stack inside electrode plates.

Ion exchange membranes are thin films of polymeric chains containing electrically charged functional sites. These selectively charged membranes can separate ions: if the membrane is positively charged (e.g., with quaternary ammonium groups) only anions will be allowed through it and it is called an anion-exchange membrane. Similarly, negatively charged membranes (i.e., with sulfonate groups) are called cation-exchange membranes. There are also membranes that only allow monovalent cations or anions through them and reject multivalent ions: these are called monovalent-selective membranes. Such selectivity is typically obtained by adding a thin ion-exchange layer of opposite sign at the surface of the membrane.

The salt solution is fed into the electrodialysis stack through the diluate circuit (and possibly through the concentrate circuit as well). When the solution arrives in the active area of the cells, the DC voltage causes the positively charged cations to migrate toward the cathode and the negatively charged anions to migrate toward the anode. When the ion reaches an ion exchange membrane, the membrane properties determine whether the ion is rejected or allowed to pass through. The ions that can pass though the membranes are retained in the next compartment because the next membrane in its path will be of the opposite charge. Therefore, there are compartments from where the ions are removed and some where they are concentrated: if the solutions are circulated rapidly through the stack, a diluate and a concentrate stream are obtained.

The low amount of water transported with the salt across the membranes, or concentration transport, enables the brine stream to have a higher concentration than the feed stream. Therefore, it is possible not only to remove salts from a solution, but also to concentrate it by electrodialysis, as does evaporation. As for most processes, there are practical limits to the desalting and concentration rates.

Many other parameters influence the design of suitable electrodialysis processes, such as temperatures, product purity, cleaning, pH, etc. The maximum temperature in electrodialysis stacks used to be 40°C, but recently developed membranes allow operation at temperatures up to 60°C, which is useful for viscous and low-conductivity products, such as sugars. Membrane fouling and stack plugging can be caused by many impurities in the feed products, either soluble or insoluble, such as organic matter, colloidal substances, microorganisms (yeast, bacteria, etc.), insoluble salts, etc. A good pretreatment step is often necessary using microfiltration, nanofiltration, and or ion exchange resins. It is also possible to clean the membranes in the stacks with dilute acids and caustic, as well as enzyme solutions. In many cases, if chemical cleaning is not enough, current reversal also has a cleaning effect to remove contaminants from membranes. The pH of the products is also a consideration as some membranes cannot tolerate very caustic solutions. Also, the membranes cannot tolerate many organic solvents and most oxidizing chemicals. The following factors may limit the implementability and effectiveness of electrodialysis:

- Concentration factor limiting
- Periodic cleaning requirements
- Pretreatment for foulants
- Flow rate limitations
- Extensive treatability testing.

Because of the high expected flow rates, the nonspecific selectivity, the need for pretreatment, and the lack of information concerning the treatment of Sr-90, electrodialysis will not be retained for further evaluation.

3.2.4.6.1.3 Electrodeionization—This new technology is a combination of electrodialysis and ion exchange, resulting in a process which effectively deionizes water while the ion exchange resins are continuously regenerated by the electric current in the unit. This electrochemical regeneration replaces the chemical regeneration of conventional ion exchange systems.

The module consists of a number of cells between two electrodes. Each cell consists of a polypropylene frame onto which are bonded a cation-permeable membrane on one side and an anion-permeable membrane on the other. The space in the center of the cell, between the ion-selective membranes, is filled with a thin bed of ion exchange resins. The cells are separated from one another by a screen separator. The feed water entering the module is split into three parts. A small percentage flows over the electrodes, 65-75% of the feed passes through the resin beds in the cell, and the remainder passes along the screen separator between the cells.

The ion-exchange resins capture dissolved ions in the feed water at the top of the cell. Electric current applied across the module pulls those ions through the ion-selective membrane towards the electrodes. Cations are pulled through the cation-permeable membrane towards the cathode, and anions are pulled through the anion-selective membrane towards the anode. These ions, however, are unable to travel all the way to their respective electrodes because they come to the adjacent ion-selective membrane, which is of the opposite charge. This prevents further migrations of ions, which are then forced to concentrate in the space between the cells. This space is known as the concentrate channel, and the ions concentrated in this area are flushed out of the system to the drain.

The channel running through the resin bed in the center of the cell is known as the dilute channel. As water passes down this channel, it is progressively deionized. At the lower end of the dilute channel, where water is free of ions, splitting of H_2O occurs in the electric field. This generates H^+ and OH^- which regenerate the ion exchange resins, effectively eliminating chemical regeneration.

The following factors may limit the implementability and effectiveness of electrodeionization:

- Pretreatment for foulants (this is rather extensive, consisting of RO or equivalent)
- Flow rate limitations, 7.5 – 20 gpm/stack
- Extensive treatability testing
- Periodic cleaning requirements.

Because of the high expected flow rates, the nonspecific selectivity, the need for pretreatment, and the lack of information concerning the treatment of Sr-90, electrodeionization will not be retained for further evaluation.

3.2.4.6.1.4 Reverse Osmosis—RO can be used to remove dissolved constituents from water. RO separates dissolved materials in solution by mechanical pressure filtration through a semipermeable membrane. The pressure must be greater than the natural osmotic pressure caused by the dissolved materials in the water. The membrane separates the influent water into two streams: the permeate that is low in total dissolved solids and the reject that is high in total dissolved solids. An RO unit consists of several modules to which feed water is added through a high-pressure pump. The feed water must be pumped at a pressure high enough to maintain the design pressure difference in the last module. The difference between the system and osmotic pressure is usually around 145 pounds per square inch (psi) with a maximum system pressure of 800 psi. Current RO technology likely cannot meet the Sr-90 MCL of 8 pCi/L; however, RO may be an effective pretreatment.

An important RO design consideration is the need to dispose, recycle, or reuse both the permeate and reject, because complete separation of solute from solvent (water) is not possible. The permeate is expected to meet the criteria for direct discharge to a percolation pond. Removal levels obtainable are dependent on membrane type, operating pressure, and the specific COC. The RO membranes may be clogged by constituents found in the INTEC groundwater. An RO system for treatment of the Sr-90 contaminated groundwater at the INTEC would likely require a pretreatment system to adjust the system's pH for scale control.

An RO system in combination with an evaporator system was initially designed to remediate groundwater plumes at the Savannah River Site. Two water treatment units were designed and built for plumes with primary COCs of strontium, I-129, uranium, and technetium from Savannah River Site groundwater (WSRC 1995). The RO process was the front-end process of the treatment units. The water treatment units were constructed in 1997, and the basic design consisted of (1) RO concentration; (2) chemical addition, neutralization, precipitation, polymer addition, flocculation, and clarification of the RO concentrate; and (3) final polishing of the clarified water by ion exchange (IX) and sorption (Serkiz et al. 2000). In October 2003, Savannah River Site decided to forgo the water treatment units in favor of more passive treatment of groundwater (e.g., pH adjustment).

The following factors may limit the implementability and effectiveness of RO:

- RO alone likely cannot achieve the very low Sr-90 effluent concentrations required to meet MCLs.
- High capital and operating costs due to required high pressures.

- Managing the reject water may be problematic.
- High level of pretreatment is required in some cases.
- Membranes are prone to fouling, requiring a periodic treatment program.
- Ability to achieve a suitably high recovery, i.e., ratio of permeate to reject.

RO is retained for further consideration.

3.2.4.6.1.5 Oxidation/Reduction—Oxidation and reduction reactions occur in pairs to compose an overall redox reaction. The addition of oxidation and/or reduction agents or DC to extracted groundwater may promote speciation or precipitation.

Chemical oxidation/reduction is typically conducted in mixing tanks or plug flow reactors. The oxidation/reduction agents may also be added to larger bodies of water in some cases. The contaminated water enters one end of the tank or reactor and exits the opposite end. The oxidation/reduction agent is either injected into the contaminated water immediately prior to entering the tank or reactor or is introduced directly into the tank. Mechanical agitation, pressure drop, or bubbling of the oxidizing agent in the tank is necessary to ensure complete mixing of the oxidizing agent. Complete mixing, which prevents short-circuiting in the tank, is necessary to ensure contact of the contaminants with the oxidizing agent for a minimum period of time, which reduces the chemical dosage required to obtain a specific effluent concentration.

The following factors may limit the implementability and effectiveness of oxidation/reduction:

- Temperature and pH
- The presence of catalysts
- Hazardous byproducts
- Concentration of other reactants
- The type of oxidizing agent that would impact process performance.

The use of oxidation/reduction systems to remove Sr-90 has not been specifically demonstrated; therefore, oxidation/reduction will not be retained for further evaluation as a primary technology.

3.2.4.6.1.6 Chemical Precipitation/Coprecipitation—Precipitation is widely used in numerous applications for removing dissolved metals and radionuclides from liquid waste streams. The chemical equilibrium of the groundwater is altered to reduce the solubility of the undesired constituents so that they precipitate as a solid phase. Changes in the pH or temperature can change the solubility equilibrium to induce precipitation, or a chemical additive can be used to react with the contaminant in solution to form a precipitate.

The precipitated solids may require the addition of a flocculent to increase the size of the solids for separation from the waste stream, or the particles may be of sufficient density and/or size to precipitate without the addition of a coagulant. Testing may be necessary to determine the growth characterization of precipitates. Sedimentation, centrifuges, or filtration (including magnetic filtration) are normally used following precipitation and flocculation to separate the solids from the supernate.

Precipitation methods require significant amounts of monitoring because small changes in the feed solution properties can significantly affect the precipitation process. This method of treatment can also produce significant quantities of solids requiring dewatering and disposal. Data from Serkiz et al. (2000) show mediocre decontamination factors, e.g., less than 5, for beta contributors, including Sr-90.

The following factors may limit the implementability and effectiveness of chemical precipitation/coprecipitation:

- The flow rates discussed previously, ranging from about 300 to 3,000 gpm, require large systems.
- Small changes in the feed solution properties can significantly affect the precipitation process.
- Some groundwater constituents may interfere with precipitation chemistry, and unanticipated compounds may precipitate.
- Due to the groundwater total dissolved solids, this method of treatment can produce significant quantities of solids requiring dewatering and disposal.
- Treatability studies are needed for specific applications, such as flocculation kinetics, to determine residence time and other parameters.

Precipitation will not be considered for further evaluation due to the lack of data available and the need for extensive treatability testing.

3.2.4.6.1.7 Freeze Crystallization—Freeze crystallization involves the removal of contaminants when freezing contaminated water. When the solution is slowly frozen, water crystals form on the surface, from which they are separated from the remaining solution. Freeze crystallization is based on the principle that impurities are generally one to two orders of magnitude more soluble in the liquid phase of a solvent than in the solid phase. Because there is no chemical difference between radioactive isotopes and their stable counterparts, the separation of radioactive isotopes is expected to be identical to the corresponding stable isotope. This principle was used to study brine drainage from ice using radioactive sodium as a tag.

The following factors may limit the implementability and effectiveness of freeze crystallization:

- In freeze crystallization, eutectic mixtures form when solutions become more concentrated. Feed stream must be dilute enough to accomplish significant volume reduction before a eutectic mixture forms. High capital costs are associated with the process, depending on the operation, facility size, and construction materials. The capital costs can be two or three times higher than the costs of evaporation or distillation systems.
- Production hangups can occur because of the complexity of the process used to control crystal size and stability. Eutectic conditions can occur where more than one material crystallizes at the same time.
- Buildup on the vessel walls of the crystallizer, or fouling, eventually occurs and requires system shutdown to allow foulant removal.

Freeze crystallization has not been demonstrated to meet MCLs for the radionuclides of concern. For this reason and due to the considerations listed above, freeze crystallization is not retained for further evaluation.

3.2.4.6.1.8 Adsorption—Adsorption is using a solid material to adsorb a dissolved species from groundwater due to an affinity to the adsorbent's surface.

Activated alumina adsorption is effective for removal of some anions not readily removed by ion exchange. Target contaminants are removed from the groundwater via adsorption of the contaminant molecules on the active adsorption sites on the alumina surface via physical and/or electrochemical attraction. The groundwater is pumped through vessels containing activated alumina, similar to the ion-exchange process. The use of activated alumina adsorption for removal of heavy metals and/or radionuclides has not been documented, except for the removal of arsenic and selenium. Therefore, the process option of activated alumina adsorption will not be retained for further evaluation.

Some studies have been performed on hydrous iron oxide gels. These indicate that pH has a large effect on the adsorption of several metal cations and anions onto iron oxide (Kinniburgh, Jackson, and Syers 1976). The extent of adsorption for metal cations increases with increasing pH and vise versa for anion adsorption.

Limestone has also been considered as a material that is good at adsorbing metals. A pilot test was performed to provide data required to assess the applicability of limestone in groundwater treatment. The demonstration unit consisted of several columns of limestone with different total column lengths and thus different residence times. Groundwater from the basins was passed through each column and analyzed for metals, radionuclides, ions, pH, and alkalinity. The results from both the laboratory and field tests show the limestone's effectiveness as a treatment medium (Ekechukwu et al. 2001).

Apatite II [$Ca_{10-x}\,Na_x(PO_4)_{6-x}(CO_3)_x(OH)_2$ where $x < 1$] has been developed from fish bones as the most reactive, most cost-effective apatite or phosphate available. This technology has been successful with contaminated range soil, groundwater, and wastewater for Pb, U, Cd, Zn, Al, and Cu and has stabilized between 5% and 50% of its weight in metals depending upon the metal and the environmental conditions (Wright et al. 2004).

Montmorillonite, kaolin, tobermorite, magnetite, silica gel, and alumina were used as the economical adsorbents to wastewater containing Cd(II), Cr(VI), Cu(II), and Pb(II). This removal method of heavy metals proved highly effective as removal efficiency tended to increase with increasing pH and decrease with increasing metal concentration. The removal percentages by adsorption onto montmorillonite, tobermorite, magnetite, and silica gel showed high values for all metals (Katsumata et al. 2003).

The following factors may limit the implementability and effectiveness of using these as adsorbents:

- pH adjustments will be needed to allow these adsorbents to work at their best. These pH ranges need to be determined through testing.
- Many of these adsorbents have been tested on various metals, but data on strontium adsorption seem to be lacking.
- Adsorbents require disposal and may not be specific enough to be cost-effective.

Adsorption will not be retained for further consideration, based on the factors listed above.

3.2.4.6.1.9 Complexation or Chelation—The process of complexation or chelation is commonly used in conjunction with ultrafiltration to separate solutes from a solvent (water) on the basis of molecular size and shape by passing the solution through a membrane module where a pressure difference is maintained across the membrane. Chelation agents are added to the water to form ligands that enhance contaminant size and mobility during extraction. The ligands (chelating polymers plus metal ions) have a higher molecular weight than the metal ions alone and are unable to pass through the pores of the membrane. Water and small molecules move through the membrane to the lower-pressure side, while the larger molecules are retained by the membrane.

The following factors may limit the implementability and effectiveness of chelation:

- Is typically used only as a pretreatment for filtration.
- A reject solution with chelated metals needs to be disposed.

No specific process was identified that would be applicable to chelation. Chelation may help groundwater extraction by mobilizing Sr that may have a high K_d with sediments in the SRPA. However, this complex may need to be broken to remove Sr from the water if the complex is neutral. Therefore, chelation is not retained.

3.2.4.6.1.10 Solvent Extraction—Solvent extraction uses countercurrent organic extractants in a carrier diluent to extract COCs from the aqueous phase (Oh 2001). Testing has been successful with high concentrations. The Sr-90 for groundwater is approximately 40 pCi/L translating to 2.9×10^{-7} μg/L for Sr-90. This concentration is too low for solvent extraction.[c]

The following factors may limit the implementability and effectiveness of solvent extraction:

- Concentration, i.e., needs to be large
- Extensive adjunct processes
- Large flow rate.

Because this technology is not effective for small concentrations, it is not considered further.

3.2.4.6.2 Physical—

3.2.4.6.2.1 Filtration—There are three categories of filtration: microfiltration, nanofiltration, and ultrafiltration. Nanofiltration is a special process selected when RO and ultrafiltration are not the ideal choice for separation. Nanofiltration can perform separation applications that are not otherwise economically feasible, such as demineralization, color removal, and desalination. In concentrations of organic solutes, suspended solids, and polyvalent ions, the permeate contains monovalent ions and low-molecular-weight organic solutions like alcohol. Ultrafiltration is a selective fractionation process using pressures up to 145 psi (10 bar). It concentrates suspended solids and solutes of molecular weight greater than 1,000. The permeate contains low-molecular-weight organic solutes and salts. Ultrafiltration is widely used in the fractionation of milk and whey and also finds application in protein fractionation. Microfiltration is a low-pressure cross-flow membrane process for separating

c. Todd, Terry A., Battelle Energy Alliance, personal communication with Samuel C. Ashworth, Battelle Energy Alliance, March 16, 2005.

colloidal and suspended particles in the range of 0.05-10 microns. Microfiltration is used for fermentation broth clarification and biomass clarification and recovery.

Ultrafiltration separates solutes from a solvent (water) on the basis of molecular size and shape by passing the solution through a membrane module where a pressure difference is maintained across the membrane. Water and small molecules move through the membrane to the lower-pressure side, while the larger molecules are retained by the membrane. To prevent fouling, the solution is passed at a high velocity over the membrane, resulting in low separation efficiencies. To improve the separation efficiency, the feed water is recycled through the ultrafiltration unit several times or passed through several modules in series.

In ultrafiltration, solutes of molecular weight greater than about 500 g/mole and less than 500,000 g/mole can be separated from a solution. The lower limit is related to the pore size of commercially available membranes. Solutes above the upper limit of molecular sizes are no longer separated from solution by ultrafiltration, but by conventional filtration. Due to the lower osmotic pressures of the high-molecular-weight solutes separated by ultrafiltration membranes, the operating pressure differences are lower than those used in RO, in the range of 5 to 100 psi (LaGrega, Buckingham, and Evans 1994).

The process options of complexation and ultrafiltration or nanofiltration have not been successfully demonstrated to remove Sr-90 from groundwater to acceptable levels. Microfiltration is likely to be an intermediate step, e.g., microfiltration could be used as a second step to precipitation without a flocculent. The following factors may limit the implementability and effectiveness of filtration:

- May require pretreatment steps – precipitation and flocculation (primary process)
- May require filter aids as an adjunct process.

Filtration process options are retained for further consideration, primarily for pretreatment.

3.2.4.6.2.2 **Evaporative Treatment—**Evaporative treatment involves pumping groundwater (treated or untreated) to a lined evaporation pond, to collection tanks for subsequent evaporation at the PEW evaporator system at the INTEC, or to a new evaporator/distillation column. Evaporation may be used either for treatment of extracted groundwater or for disposal of treated water or liquid secondary wastes. Several evaporative treatment and/or disposal options are discussed below.

3.2.4.6.2.2.1 Process Equipment Waste Evaporator System— Contaminated groundwater or treatment process concentrates could be transported or piped to the existing PEW evaporator at the INTEC, if the evaporator has the capacity to handle the volume of water generated by a groundwater extraction system. Use of the PEW evaporator to process the volume of contaminated groundwater that will be produced by the extraction system would require a modification of the current permit, which limits influent capacity to 500 gph (1,900 L/hr). Also, the influent capacity may likely be shared with other users. This is obviously far less than the flow needed to evaporate the entire groundwater flow.

Evaporative treatment of groundwater may be used in conjunction with other treatment options to treat ion exchange regenerants or other process concentrates. However, the treatment process concentrate would likely exceed the PEW evaporator WAC for chloride. Therefore, evaporative treatment via the PEW evaporator is not retained for further evaluation.

3.2.4.6.2.2.2 New Evaporation Ponds—Annual evaporation demand at the INL Site ranges from 40 to 46 in. per year NOAA (1989). Evaporation demand can be used to remove water discharged to lined ponds. The net evaporation rate from the pond(s) must meet or exceed the inflow rate to the pond, and leakage from the pond must be prevented using geosynthetic liners, potentially in combination with compacted clay layers.

Evaporation removes essentially pure water, leaving solutes, including contaminants, in the pond bed. The residues containing the contaminants would be removed and transported for disposal at an ICDF-equivalent on-Site or off-Site disposal facility.

Ponds would have to be sized such that evaporation exceeded inflow to the pond, including precipitation, with provisions for reduced evaporation in cooler months. Precipitation and wind from a design storm event would have to be accounted for. Treatment and/or disposal of treated groundwater or concentrates in new evaporation ponds are considered potentially effective and feasible.

3.2.4.6.2.2.3 Existing ICDF Evaporation Pond—This option would involve piping extracted groundwater, or treated water or concentrates, to the existing ICDF evaporation ponds. The ICDF evaporation ponds were designed to receive leachate from the ICDF landfill cells. The evaporation ponds will accept waste streams that include

- Leachate generated from the ICDF landfill
- Decontamination water from the Staging, Storage, Sizing, and Treatment Facility unit
- Other CERCLA liquid wastes from the INL Site that have been characterized and have an approved waste profile.

Treated OU 3-14 groundwater and treatment system concentrates would potentially meet the definition of CERCLA liquid waste. EDF-ER-271 presents design calculations performed to ensure that overtopping will not occur in the event of a design storm and also that sediments remain covered by water to prevent airborne migration of dry contaminants. This design document determined that up to 7 gpm of makeup water might be needed between May and October and none in the winter and spring months. Given this relatively low requirement for additional water, very little additional flow would probably be allowed to maintain adequate freeboard in the ponds. Additionally, the pond would likely not be available when required, based on the current ICDF closure schedule. Implementability of disposal of treated groundwater or concentrates in the ICDF evaporation ponds is therefore considered low and this option is not retained for further consideration.

3.2.4.6.2.2.4 New Evaporator or Distillation System—A new evaporation/distillation system would concentrate the contaminants, and the concentrate would be stored for future treatment. The volume of waste would be reduced by using a new system. The distillation system is similar to the existing PEW system except that there would be several plates or bubble caps and a reflux.

High flow rates and low contaminant concentrations may limit the implementability and effectiveness of evaporation. However, evaporative treatment of groundwater may be used in conjunction with other treatment options to reduce the volume of material to be treated. Therefore, evaporative treatment in a new evaporator or distillation system will be retained for further evaluation.

3.2.4.6.3 Thermal—Thermal systems use high-temperature processes such as cement kilns, pyrolysis, molten glass (vitrification), plasma arc, and incineration. These are not applicable to low concentrations of metals (Freeman 1989) and radionuclides dissolved in water.

The following factors may limit the implementability and effectiveness of thermal processes:

- Usually not applicable with aqueous solutions containing contaminant metals.
- Concentration and amount of water; a sludge that is produced might be acceptable.

Based on the discussion above, thermal methods are not retained for further evaluation.

3.2.4.6.4 Biological Treatment—Conventional liquid-phase treatment consists of technologies or variants originally developed for treatment of industrial wastewater. The technology consists of passing extracted groundwater through a bioreactor containing either suspended or attached biomass of highly active and acclimated microorganisms. The contaminants are put into contact with microorganisms through attached or suspended biological systems or constructed wetland-based systems. The microbial population for the attached or suspended systems may either be derived from the contaminant source or from an inoculum or organisms specific to a contaminant. Attached and suspended systems are often used together.

Bioreactors are used primarily to treat nonhalogenated volatile and semivolatile organics and fuel hydrocarbons. Halogenated volatiles and semivolatiles, pesticides, metals, and radionuclides can also be treated, but the process may be less effective and may be applicable only to some compounds within these groups.

3.2.4.6.4.1 Algal Cells in Silica Gel—This is a biosorption process for removing toxic metal ions or radionuclides from water. Biological materials (algal cells) have a strong affinity for radionuclides and metal ions. Contaminated water is passed through a silica gel matrix containing algal cells. Contaminants are sorbed onto the algal cells. The biomass must be further treated or disposed of.

3.2.4.6.4.2 Fixed Bacterial Film—This bioremediation process uses an attached-growth film (an inert media). Contaminated water is passed through a bioreactor which houses the media. The process is a sorption process for removing toxic metal ions or radionuclides from water based on the strong affinity of biological materials for heavy-metal ions. The contaminated water passes over the fixed film of bacteria and the bacteria accumulate the metals or radionuclides. The biomass must be further treated or disposed of.

3.2.4.6.4.3 Wetlands-Based Treatment—Bioremediation systems have been constructed in the form of artificial wetlands, consisting of shallow basins lined with an impermeable barrier, filled with loam and sand, and planted with reeds and other vegetation. Contaminated groundwater is pumped or allowed to flow through the artificial wetland. Organic carbon for bacterial sustenance is supplied by senescent roots and decaying plant matter. This process was originally developed to treat water with high nitrate concentrations. Constructed wetlands also remove many heavy metals, though they are not destroyed, but are immobilized and concentrated in wetland sediment.

3.2.4.6.4.4 Phytoremediation—Phytoremediation is the use of vegetation for treatment of contaminated soil, sediment, and water (normally in situ). It is applicable at sites containing organic, nutrient, or metal pollutants that can be accessed by the roots of plants and sequestered, degraded, immobilized, or metabolized in place (Schnoor 2002). For metal contaminants, phytoextraction has been used (i.e., uptake and recovery of metals into aboveground biomass at waste sites). Filtering metals from water onto root systems has also been successful (Dushenkov et al. 1995), and stabilizing wastes by hydraulic control (phytostabilization) is a widely recognized strategy (Salt et al. 1995; Dushenkov et al. 1995; Salt et al. 1997). A periodic table is provided (Schnoor 2002) showing that Sr is amenable to phytoremediation, given the chemical similarities with calcium. Hanford is considering phytoremediation for groundwater (in situ) near the Columbia River for Sr-90.

The following factors may limit the implementability and effectiveness of the biological treatment systems:

- Solid residuals from sludge processes may require further treatment or disposal.
- The precipitation of iron may clog treatment systems unless a magnetic filtration process is incorporated.
- Wetland-based remediation rates and efficiency are affected by seasonal variations (especially winter).
- Constructed wetlands may require closure as waste unit.

Because of the high expected flow rates, the low concentrations, and the lack of information concerning the treatment, biological treatment will not be retained for further evaluation.

3.2.4.7 Disposal. Many of the SRPA ex situ treatment process options discussed previously would generate secondary wastes, in addition to treated groundwater. Secondary wastes would likely include a concentrate that contains the contaminants extracted from the groundwater, in the form of a brine, reject solution, or precipitated sludge. Solid wastes could also be produced, including resins that can no longer be regenerated, activated carbon, filter media, or other materials.

Temporary storage pending disposal could be required for both solid and liquid wastes. Liquid storage could include drums or storage tanks. Solid storage could include drums or other containers that meet the ICDF WAC.

Solid wastes would be disposed of at the ICDF or an equivalent on-Site or off-Site facility as discussed previously for contaminated soil and are not discussed further. Appropriate disposal options for all liquid concentrates and treated groundwater include existing INTEC percolation ponds, discharge to INTEC STP, reinjection wells, existing evaporation pond, and new evaporation pond. Existing ICDF evaporation ponds and new evaporation ponds are discussed above with ex situ treatments.

3.2.4.7.1 Disposal to INTEC Existing Percolation Ponds—This option would involve combining treated groundwater and/or treatment process concentrates with existing service waste flows and piping the combined flow to the INTEC percolation ponds, which began use in 2003, via the existing piping system. During normal operations, INTEC generates an average of 1 to 2 mgd of process wastewater (commonly called service waste) that is discharged to the new percolation ponds, located approximately 11,000 ft west of the INTEC fence. The service waste system serves all major facilities at INTEC. This process-related wastewater from INTEC operations consists primarily of steam condensates, noncontact cooling water, RO products, water softener and demineralizer regenerate, and boiler blowdown wastewater (DOE-ID 2004c).

The service waste system consists of a network of approximately 5,600 ft of piping within INTEC with mains ranging from 8 to 20 in. in diameter. The laterals from the various facilities generally consist of lines that are 1.5 – 4 in. in diameter and are made from carbon steel, stainless steel, and Bondstrand. The laterals and smaller mains are gravity-fed. Service waste is collected in a series of manholes and fed to CPP-797 where it is pumped via a redundant pumping system rated at 2,080 gpm. From CPP-797, the service waste is pumped through 14- and 16-in.-diameter HDPE mains along the west side of INTEC where it is then routed via two 16-in.-diameter HDPE lines to percolation ponds.

The new INTEC percolation ponds are a rapid infiltration system comprised of two ponds excavated into the surficial alluvium and surrounded by bermed alluvial material. Each pond is approximately 93 × 93 m (305 × 305 ft) at the top of the berm and is about 3 m (10 ft) deep. Each pond is designed to accommodate a continuous wastewater discharge rate of approximately 11 ML/day (3 mgd). The percolation ponds receive only nonhazardous wastewater and do not receive sanitary wastes.

During normal operation, wastewater is discharged to only one pond at a time to minimize algae growth and maintain good percolation rates. Ponds are routinely inspected, and the water depth is recorded via permanently mounted staff gauges.

The technical implementability of disposal to the INTEC percolation ponds would depend primarily on the volume of flows in the service waste and SRPA treatment systems. Assuming a peak service waste flow of 2 mgd (1,390 gpm) only about 840 gpm of excess pumping capacity would be available, based on the pumping rate of 550 gpm for the extraction system discussed in Section 3.2.4.5.1. If flows from the SRPA treatment system were less than 840 gpm, this option could potentially be technically feasible. Quality of the treated water and, potentially, the treatment process concentrates would be acceptable for disposal at the INTEC percolation ponds.

3.2.4.7.2 Disposal to the INTEC STP—The INTEC sanitary sewer system is based upon a gravity-fed network of 4- to 12-in.-diameter pipelines totaling approximately 14,200 ft. Due to the size of the system, five lift stations are necessary to transport the effluent to the STP. There are also five active septic fields serving smaller support facilities located at various areas within INTEC. Additionally, the ICDF, located outside the southwest corner of INTEC, pumps sanitary waste into the INTEC sanitary system manhole located on the west side of INTEC.

The STP was built in 1982 and has a capacity of 80,000 gpd through its four treatment lagoons. The treated effluent is discharged to the service waste system percolation ponds located west of INTEC in order to meet wastewater land application permit requirements. During the last year, the STP produced approximately 1,620,000 gal of effluent. The plant is not permitted to treat radionuclide-contaminated influents.

Estimated groundwater pumping rates would greatly exceed the current plant capacity of 80,000 gpd (56 gpm). Concentrations of radionuclides in treatment system concentrates would violate the wastewater land application permit. Implementability of disposal of treated groundwater or concentrates in the INTEC STP is therefore considered low.

3.2.4.7.3 Reinjection of Treated Water into the Snake River Plain Aquifer— Treated water could be returned to the contaminated zone of the SRPA via injection wells if improvement was made to the water quality; or the treated water could be injected to the SRPA at a location outside the contaminated zone if all the water quality criteria are met. One or more wells screened across the water table would be used, depending on flow rates. Water can be reinjected upgradient of the injection well to increase the hydraulic gradient across the capture zone of the extraction well or reinjected downgradient so as to have no effect.

Reinjection of treated water is technically feasible and is retained for further consideration.

3.2.5 Summary of Retained Remedial Technologies for Groundwater

Table 3-3 summarizes OU 3-14 SRPA remedial technologies retained after screening. GRAs including ICs, surveillance and monitoring, containment, removal, ex situ treatment, and disposal, were identified. The ICs GRA will be used to identify a baseline alternative to which others will be compared.

Remedial technologies, including administrative controls, access restrictions, and property transfer controls, were retained for further consideration. Groundwater monitoring was also retained.

Remedial technologies for groundwater containment, including interceptor and/or recharge trenches, vertical barriers, and horizontal barriers were screened out. Extraction and/or injection wells were retained for further consideration.

All of the SRPA in situ treatment technologies considered, including biological and physicochemical, were screened out.

Extraction wells were the only groundwater removal technology retained for consideration.

Ex situ treatment technologies, including electrodialysis, electrodeionization, electrolytic oxidation-reduction, chemical precipitation, freeze crystallization, carbon adsorption, adsorption on activated alumina, chelating agent, solvent extraction, treatment in the PEW, thermal treatment, evaporative treatment in the ICDF evaporation pond, and all biological treatments, were screened from further consideration. Ion exchange, RO, chemical oxidation-reduction, carbon adsorption, filtration, and two evaporative treatments (new evaporation pond and a new evaporator or distillation system) were retained for further consideration.

Discharge to the INTEC STP was eliminated as a treated groundwater disposal technology. Discharge to the existing percolation ponds, an injection well, or a new evaporation pond, as well as storage in tanks or drums, were retained.

3.3 Evaluation of Remedial Technologies and Process Options

Technologies retained following the initial screening in Section 3.2 are evaluated with respect to effectiveness, implementability, and relative cost in this section. The objective of this evaluation is to provide sufficient information for subsequent selection of representative process options (RPOs) in Section 3.4. No technologies are screened out at this stage.

Effectiveness is the most important criterion at this evaluation stage. The evaluation of effectiveness was based primarily on the following:

- The potential effectiveness of process options in handling the estimated areas or volumes of contaminated media and meeting the RAOs
- The potential impacts to worker safety, human health, and the environment during construction and implementation
- The degree to which the processes are proven and reliable with respect to the contaminants and conditions at the site.

The evaluation of implementability includes consideration of the following:

- The availability of necessary resources, skilled workers, and equipment to implement the technology
- Site accessibility and interfering infrastructure
- Potential public concerns regarding implementation of the technology

- The time and cost-effectiveness of implementing the technology in the physical setting associated with the waste unit.

A relative cost evaluation is provided for comparison among technologies. Relative capital and O&M costs are described as high, medium, or low. These costs are based on references applicable to the particular process option given at the end of this section, prior estimates, previous experience, and engineering judgment. The costs are not intended for budgetary purposes.

3.3.1 Evaluation of Process Options for the Tank Farm Soil

3.3.1.1 Institutional Controls.

Effectiveness. ICs can effectively control exposures as long as they are implemented. Passive ICs, e.g., deed restrictions and permanent markers, are assumed to remain effective for the duration of risk. Active ICs, e.g., guards and fences, are assumed to not be effective after 2095. RAOs III and IV would be met.

Implementability. ICs are currently implemented at the tank farm. Passive institutional controls are assumed to be implementable for the duration of risk; however, active ICs are assumed to not be implementable after 2095.

Cost. ICs have relatively low capital and O&M costs.

3.3.1.2 Monitoring.

3.3.1.2.1 Surface Soil Sampling—

Effectiveness. Surface soil sampling can determine extent of Cs-137 and Sr-90 contamination and attainment of RGs. Soil sampling would not meet RAOs but could in combination with other technologies.

Implementability. With adherence to an approved health and safety plan, few implementability concerns are associated with continued monitoring of shallow soil (0 to 4 ft deep at the tank farm and 0 to 10 ft deep for CPP-58) through 2095. Surface soil sampling at CPP-15 will be impeded until the electrical duct bank and transformers over the site are removed, which is planned for 2035. However, contaminants will remain in tank farm soil above risk-based levels after 2095, and implementability of long-term soil monitoring after 2095 at the tank farm is uncertain.

Cost. Costs for soil sampling and analysis are moderate to high.

3.3.1.2.2 In Situ Gamma Monitoring—

Effectiveness. In situ gamma monitoring sampling can determine extent of Cs-137 contamination and attainment of RGs. Gamma monitoring would not meet RAOs but could in combination with other technologies.

Implementability. With adherence to an approved health and safety plan, few implementability concerns are associated with continued monitoring at the tank farm through 2095. However, contaminants will remain in tank farm soil above risk-based levels after 2095, and implementability of long-term soil monitoring after 2095 at the tank farm is uncertain.

Cost. Costs for in situ gamma monitoring are relatively low.

3.3.1.3 Containment. The types of containment systems that were retained from Section 3.2.2.3 included the RCRA caps, ET covers, rock armor, Hanford barrier, concrete cap, conventional asphalt, MatCon asphalt, flexible membrane caps, and maintenance of the TFIA. The following is an evaluation of each type of containment system.

3.3.1.3.1 RCRA Subtitle C Cover—

Effectiveness. The RCRA Subtitle C cover can effectively limit moisture infiltration and thereby reduce Sr-90 flux to the SRPA and potentially help to meet RAOs I and II. This barrier would require a thick surface soil layer to provide adequate soil moisture storage to sustain plants. Overall thickness of the barrier can be designed to provide a clean soil barrier greater than the future worker intrusion depth of 4 ft (RAO III). A RCRA Subtitle C would likely retain these functions for the duration of risk, i.e., 117 years for infiltration control and 220 years for worker protection. The thickness of the cover and the membrane liner and compacted clay or geosynthetic clay would deter biointrusion (RAO V). Maintenance of the vegetated soil surface of the cap, e.g., filling animal burrows, would be required.

Implementability. Implementability of any barrier on the tank farm will be constrained by infrastructure and operations as described in Section 1. The RCRA cover could only be implemented after 2012 on the central tank farm and after 2035 for the entire tank farm area.

The constructability of the RCRA cover is considered moderate. Use of geosynthetic materials would make staged construction more difficult. Surface barrier construction is similar to other types of earthwork, such as highway construction, with respect to complexity and expertise required. No specialized equipment, personnel, or services are required to implement this alternative. Construction materials are readily available at the INL Site or from other local sources.

Cost. A RCRA cover has relatively moderate capital costs and relatively moderate O&M costs.

3.3.1.3.2 ET Cover—

Effectiveness. ET covers have been demonstrated to provide equivalent infiltration control performance to RCRA covers under arid climate conditions and could therefore potentially help to meet RAOs I and II. These cover types are built almost entirely using native earthen materials; therefore, service life is estimated to exceed that for RCRA covers and approach that for the Hanford barrier. The thickness of the barrier (about 5-7 ft) is more than sufficient to provide a clean soil barrier greater than the future worker intrusion depth of 4 ft (RAO III) and would reduce the potential for biointrusion (RAO V). An ET cover would likely retain these functions for the duration of risk, i.e., 117 years for infiltration control and 220 years for worker protection. The thickness of the cover would deter biointrusion (RAO V). Maintenance of the vegetated soil surface of the cap, e.g., filling animal burrows, would be required.

Implementability. Implementability of any barrier on the tank farm will be constrained by infrastructure and operations as described previously. An ET cover could only be implemented after 2012 on the central tank farm and after 2035 for the entire tank farm area.

The constructability of the ET cover is considered high. Lack of geosynthetic materials improves the ability to construct the ET cover in stages. Surface barrier construction is similar to other types of earthwork, such as highway construction, with respect to complexity and expertise required. No specialized equipment, personnel, or services are required to implement this alternative. Construction materials are readily available at the INL Site or from other local sources.

Cost. An ET cover has relatively low capital costs and relatively low O&M costs.

3.3.1.3.3 Rock Armor Cover—

Effectiveness. Rock armor covers can effectively inhibit human and biotic intrusion into buried waste. A rock armor cover at least 4 ft thick may therefore meet OU 3-14 RAOs III and V. Rock armor covers reduce evaporation and transpiration demand on underlying soil and thereby increase infiltration. A rock armor cover would have to be underlain with impermeable layers, e.g., a membrane and/or geosynthetic clay, to reduce infiltration through the capped area.

Implementability. A rock armor cover would only be technically implementable on the tank farm surface after sufficient surface infrastructure had been removed to allow for construction and after subsurface process lines had been removed from service. Tank farm surface loading constraints would prevent construction prior to grouting of the tanks. A rock armor cover was constructed over the SL-1 burial site and is therefore constructable using INL Site materials and personnel.

Cost. A rock armor cover has relatively low capital and O&M costs.

3.3.1.3.4 Hanford Barrier—

Effectiveness. The Hanford barrier would limit moisture infiltration and could therefore potentially help to meet RAOs I and II. The thickness of the barrier (about 15 ft) is more than sufficient to provide a clean soil barrier greater than the future worker intrusion depth of 4 ft and would thereby meet RAO III. The thickness of the barrier (about 15 ft) is more than sufficient to provide a clean soil barrier greater than the future worker intrusion depth of 4 ft (RAO III) and, in combination with the capillary/biobarrier and asphalt layers, would eliminate the potential for biointrusion (RAO V). A Hanford barrier would likely retain these functions for the duration of risk, i.e., 117 years for infiltration control and 220 years for worker protection. Maintenance of the vegetated soil surface of the cap, e.g., filling animal burrows, would be required.

Implementability. Implementability of any barrier on the tank farm will be constrained by infrastructure and operations as described in Section 1. The Hanford barrier could only be implemented after 2012 on the central tank farm and after 2035 for the entire tank farm area.

The constructability of the Hanford barrier is considered low-moderate, due to the relatively large thickness of the barrier and volume and variety of materials required. Surface loading produced by the 15-ft-thick cap would have to be considered. Surface barrier construction is similar to other types of earthwork, such as highway construction, with respect to complexity and expertise required. No specialized equipment, personnel, or services are required to implement this alternative. Construction materials are readily available at the INL Site or from other local sources.

Cost. A Hanford barrier has relatively high capital costs and relatively low O&M costs.

3.3.1.3.5 Concrete Cap—

Effectiveness. A concrete cover could reduce infiltration rates through the capped area to essentially zero and could therefore potentially help to meet RAOs I and II. A concrete cover would not reduce direct exposure risks to future workers in the absence of institutional controls (RAO III), unless it was at least 4 ft thick. The concrete cover would eliminate biointrusion for the functional life of the cover. O&M, including repair of damaged areas, would be required for the cover to remain effective.

Implementability. A concrete cover would only be technically implementable on the tank farm surface after the HLW tanks had been grouted. Concrete entombment was implemented for the WCF closure and is therefore constructable using INL Site materials and personnel, in addition to subcontracted services.

Cost. A concrete cover would have relatively high capital and moderate O&M costs.

3.3.1.3.6 Conventional Asphalt—

Effectiveness. A conventional asphalt cover with adequate seal coating could effectively reduce infiltration through the capped area and could therefore potentially help to meet RAOs I and II. An asphalt cover would not reduce direct exposure risks to future workers in the absence of institutional controls (RAO III). The asphalt cover would eliminate biointrusion for the functional life of the cover. O&M, including repair of damaged areas and repeat seal coats, would be required for the cover to remain effective.

Implementability. An asphalt cover would be technically implementable on the tank farm surface at present. An asphalt cover was previously applied for the TFIA and is therefore constructable using INL materials and personnel, in addition to subcontracted services.

Cost. An asphalt cover would have relatively low capital and moderate O&M costs.

3.3.1.3.7 MatCon Asphalt—

Effectiveness. A MatCon asphalt cover could effectively reduce infiltration rates through the capped area to essentially zero and could therefore potentially help to meet RAOs I and II. A MatCon asphalt cover would not reduce direct exposure risks to future workers in the absence of institutional controls (RAO III). The MatCon cover would eliminate biointrusion for the functional life of the cover (RAO V). O&M, including repair of damaged areas, would be required for the cover to remain effective.

Implementability. A MatCon asphalt cover would only be technically implementable on the tank farm surface after the HLW tanks had been grouted. MatCon asphalt would be applied using conventional asphalt paving equipment and is therefore constructable using INL Site materials and personnel, in addition to subcontracted services.

Cost. A MatCon asphalt cover would have relatively high capital and moderate O&M costs.

3.3.1.3.8 Flexible Membrane—

Effectiveness. A flexible membrane cover could effectively reduce infiltration rates through the capped area to essentially zero and could therefore potentially help to meet RAOs I and II. A flexible membrane cover would not reduce direct exposure risks to future workers in the absence of institutional controls (RAO III). The cover would likely be combined with a soil layer to be completely effective. O&M, including repair of damaged areas, would be required for the cover to remain effective.

Implementability. A flexible membrane cover would be technically implementable on the tank farm surface at present. A flexible membrane cover was previously applied on the tank farm in 1977 and is therefore constructable using INL Site materials and personnel, in addition to subcontracted services.

Cost. A flexible membrane cover would have relatively moderate capital and low O&M costs.

3.3.1.3.9 Maintain/Expand Tank Farm Interim Action—

Effectiveness. The TFIA is potentially effective in limiting infiltration through the asphalt surface covers constructed over CPP-31, -28 and -79; and in maintaining positive surface drainage over the tank farm via the lined drainage ditches, lift station, and evaporation pond. Maintaining the TFIA would not meet RAOs individually but could in combination with other remedies, e.g., institutional controls and capping. Maintaining the TFIA would not reduce future worker risks in the absence of institutional controls because a clean soil buffer greater than 4 ft thick would not be provided. O&M, including repairing damaged asphalt areas, clearing drainage ditches, and periodically maintaining and replacing the lift station pump, would be required for the TFIA to remain effective.

Implementability. The TFIA is currently implemented and maintained. The necessary materials and the labor force required are readily available.

Cost. Maintaining the TFIA controls has relatively low capital and O&M costs.

3.3.1.4 In Situ Treatment. The following is an evaluation of biological and physicochemical in situ treatment process options.

3.3.1.4.1 Phytoremediation—

Effectiveness. Phytoremediation could potentially reduce future worker exposures (RAO III) by removing Cs-137 from soil to a depth of 4 ft bgs; however, effectiveness in reducing soil concentrations to the future worker PRG of 92 pCi/g Cs-137 would have to be demonstrated in treatability studies. Effectiveness after the end of active maintenance is low because active harvesting, volume reduction, and disposal of vegetation would be required.

Implementability. Implementability would be low to moderate due to the presence of subsurface infrastructure and gravelly soil and the requirement for treatability studies.

Cost. Phytoremediation, including treatability studies, would have relatively moderate capital and O&M costs.

3.3.1.4.2 Atomized Apatite Injection—

Effectiveness. Apatite and soluble phosphate addition has been shown to be effective at immobilizing metal contaminants in soil (Laiti, Persson et al. 1996; Ma, Logan et al. 1994; Traina and Laperche 1999) and can form low-solubility phases with strontium. If delivered successfully, apatite may potentially immobilize residual Sr-90 in tank farm alluvium.

Implementability. The use of a high-pressure aerosol allows use of directional drilling, and the radial axis can be oriented up to 90 degrees from vertical. This technique does not depend on in situ hydrology or biogeochemistry to emplace the apatite/PO_4^{3-} barrier, and efficiency of emplacement can be estimated from cold tests in analog materials. Magnetic or conducting materials can also be injected with apatite to allow application of geophysical techniques to monitor emplacement. Implementation of the atomized injection method will require specialized equipment, trained personnel, and contracting with a private firm that owns this proprietary technology. Some pilot studies will be required to determine the most effective combination of reagents, optimum treatment conditions, and the radius of infiltration into INTEC sediments. Drilling will need to be permitted in the INTEC tank farm, likely via directional drilling beneath existing piping infrastructure and into a subsurface region lightly contaminated with Sr-90. EPA and public acceptance of in situ chemical immobilization of Sr-90 is likely to require continued monitoring for Sr-90.

Cost. A number of development issues will have to be addressed to implement the atomized apatite injection technology, and these will add to the cost. The following must be determined: how apatite is distributed relative to migrating Sr-90, how migration paths might change with seasonally variable infiltration patterns, and whether the apatite surfaces remain active for the period of time necessary to reduce the rate of Sr-90 migration. Gas-atomized apatite injection will have moderate capital costs, with the greatest costs arising from permitting and drilling operations. Costs will primarily depend on the number of directionally drilled boreholes needed and the amount of drilling equipment that can be satisfactorily decontaminated after drilling through the contaminated region.

3.3.1.4.3 CO_2 Gas Injection and Coprecipitation of Metal Carbonates—

Effectiveness. Coprecipitation of metals and radionuclides into calcite is well established and may be a feasible remediation option at the INL Site, where significant amounts of calcite already exist in the subsurface. An alternative to the addition of aqueous solutions to direct calcite precipitation is the manipulation of the soil gas composition. By adding CO_2 gas, the pH of the soil water will decrease and the solubility of calcite increase. The partial pressure of CO_2 can then be decreased to the ambient condition, resulting in precipitation of calcite and the coprecipitation of select metals and radionuclides, including Sr-90. This technique will alter the speciation of Sr-90 in the alluvium, likely resulting in a net increase of Sr-90 incorporation into calcite and significant reduction in Sr-90 K_d. The thermodynamic and kinetic principles are well established in the literature.

Implementability. The basic concept is based on well-known geochemical principles; however, the method has not been demonstrated. The use of gaseous amendments has a lower potential for mobilizing soil water than aqueous amendments, and it will be easier to control gaseous additions to the INTEC alluvium than aqueous additions. The large diffusion coefficients of gases would suggest that most of sediments with even small-to-moderate air-filled porosity will be treated, and only fine-grained material where the air-filled porosity is negligible will pose difficulties. The injection and extraction of gases in the vadose zone is a readily available technology. The installation and use of gas delivery systems are expected to have minimal impact on tank farm closure activities. Partially because of the lack of a demonstration of the approach, several research and development questions should be addressed prior to implementation. The following must be determined: what geochemical conditions in the vadose zone at INTEC are conducive to precipitation of calcite by gas-phase manipulation, what gas-phase compositions will achieve sufficient sequestration of Sr, and if there is sufficient water to achieve the needed perturbations in the system geochemistry. Demonstrations should have to show no significant mobilization of contaminants will occur as a consequence of the treatment.

Cost. The capital and O&M costs of implementation of this strategy will be moderate. Research and development costs are unknown at this time. Costs of gas amendments are expected to be low, and monitoring costs will depend on regulatory requirements.

3.3.1.4.4 Soil Vapor Extraction—

Effectiveness. Soil vapor extraction could potentially reduce Sr-90 flux to groundwater from OU 3-14 soil, by reducing soil moisture content and thereby the unsaturated hydraulic conductivity. However, the effectiveness in reducing in reducing contaminant flux would have to be demonstrated in treatability studies. The system would potentially require continued operation and maintenance after

2095. Soil vapor extraction would not reduce future worker direct exposure risks in the absence of institutional controls.

Implementability. Soil vapor extracted has been previously implemented at the INL Site SDA and is therefore constructable using INL Site materials and personnel, in addition to subcontracted services. Implementability would be low to moderate due to the presence of surface and subsurface infrastructure, and the requirement for treatability studies.

Cost. Soil vapor extraction, including treatability studies, would have relatively moderate capital and O&M costs.

3.3.1.4.5 Solidification/Stabilization—

Effectiveness. Solidification/stabilization is a proven method for treating soil to improve structural strength and reduce the leachability of radionuclides. The duration of immobilization for Sr-90 in grouted soil is unknown. Grout returns are common during injection, requiring some disposal. Because the technology is applied in situ, verifying the effectiveness of the reagent/waste mixing is difficult.

During mobilization and operation of the solidification/stabilization equipment, impacts to human health and the environment can be mitigated through the use of construction safety practices when mixing the contaminated materials. Because the media is treated in place, exposure to workers should be minimal. However, worker exposures can occur unless containment technologies are used in conjunction with the stabilization technologies.

Effectiveness depends on selection of an appropriate grout and adequate contact of the grout and contaminated soil. Cement-based grouts and WaxFix are the best candidate grouts for immobilizing Sr-90 at the tank farm. Jet grouting is the best candidate delivery method.

Implementability. Subsurface infrastructure present at CPP-31 and -79 (deep) significantly constrain implementability of in situ treatment, including solidification/stabilization. Implementation requires specialized equipment and trained personnel. Treatability studies would be required to determine the most effective reagents and optimum mixing ratios. Field demonstrations would be required to show effective contact of grout and contaminated soil in the presence of infrastructure.

Solidification/stabilization is administratively feasible. EPA and the public have previously accepted solidification/stabilization for treating radioactive wastes.

Cost. Solidification/stabilization has moderate capital and O&M costs, depending on the number of injection holes needed to stabilize a large area and the specific method selected.

3.3.1.5 Removal. Soil removal to a depth of at least 4 ft bgs and backfilling with clean soil could potentially meet RAO III. Conventional excavators and remotely controlled excavators were retained from the preliminary screening process and are evaluated below. Confinement technologies and radiation shielding will need to be used in conjunction with conventional excavation at the tank farm where high radiation fields may occur. In the case of sites where worker exposures would exceed allowable levels, excavation would potentially require the use of remotely controlled equipment. Tank farm soil removal cannot be implemented until after tank closure under RCRA. External exposure from radionuclide contaminants in the tank farm soil will reduce implementability at the tank farm.

3.3.1.5.1 Conventional Excavators—

Effectiveness. Conventional excavators are effective for excavating and handling large quantities of soil, rock, or debris and for excavating localized areas of contaminated soil. Conventional excavators would alleviate certain waste groups of inherent risks from soil contamination. Excavation, however, is generally a precursor technology for ex situ treatment and disposal.

Implementability. Conventional excavators are administratively feasible. Both the resources and the services required to provide excavation and earthmoving operations are readily available. Earthmoving equipment would require decontamination following remediation. Direct gamma radiation exposures to workers in some areas, e.g., CPP-31, would exceed allowable levels but may be reduced using shielding, longer-reach excavator arms, and shorter work shifts.

Cost. Conventional excavators generally have relatively low capital and O&M costs.

3.3.1.5.2 Remotely Controlled Excavators—

Effectiveness. Remotely controlled excavators effectively eliminate the exposure of operators when excavating in high gamma fields or other high-exposure conditions. Remotely controlled excavators can handle large quantities of soil, rock, or debris. Remotely controlled excavators would alleviate certain waste groups of inherent risks from soil contamination. Remotely controlled excavators typically can excavate less volume per day than conventional excavators.

Implementability. Remotely controlled excavators are administratively feasible. Both the resources and the services required to provide excavation and earthmoving operations are available. Remotely operated excavators require specially trained operators; however, operators require less or no contamination controls because they are not in the excavator.

Cost. Remotely controlled excavators generally have comparatively high capital and O&M costs.

3.3.1.5.3 Vacuum Excavators—

Effectiveness. Vacuum excavators can effectively reduce the exposure of operators when excavating in high gamma fields or other high-exposure conditions. Vacuum excavators typically can excavate less volume per day than conventional excavators.

Implementability. Vacuum excavators are currently used at INTEC and are therefore implementable using INL Site materials and personnel, in addition to subcontracted services.

Cost. Vacuum excavators generally have comparatively moderate capital and O&M costs.

3.3.1.6 Disposal.

Effectiveness. Disposal alone would not meet RAOs but could help meet RAO III in combination with other technologies.

Implementability. Disposal at ICDF is completely implementable through the projected closing date in 2013. Implementability after that time is uncertain.

Cost. Disposal at ICDF has relatively moderate cost. Representative costs for off-Site disposal facilities are provided in Appendix B.

3.3.2 Evaluation of Process Options for Groundwater

This section provides comparative evaluations of remedial technology process options for the SRPA, to support selection of RPOs. This discussion is organized according to the retained groundwater GRAs with specific references to the applicability of each selected process option to the SRPA.

3.3.2.1 Institutional Controls.

3.3.2.1.1 Administrative Controls—

Effectiveness. Administrative controls would effectively prevent current and future workers from being exposed to groundwater contaminated by INTEC releases, thereby meeting RAO I. Administrative controls would not be effective if institutional controls ended.

Implementability. Administrative controls including the CFLUP, public notices, DOE environmental checklists, DOE directives, notice of soil disturbances and work controls, are currently implemented and can be maintained through at least 2095.

Cost. When compared with other institutional actions, administrative controls have relatively low capital and O&M costs.

3.3.2.1.2 Fencing and Security—

Effectiveness. Fencing and 24-hour security are effective in limiting access to the INTEC or the existing wells that penetrate the SRPA and thereby meet RAO I. Fencing and 24-hour security would be effective in minimizing the potential human health risks posed by human contact with the contaminated groundwater beneath the site. However, these access restrictions would not be effective in protecting the environment and are not applicable after the IC period has ended.

Implementability. Fencing and 24-hour security are easily implemented. Fencing and 24-hour security already exist at the INTEC, and services necessary to install additional fencing and other security measures are common and readily available at the site.

Cost. When compared with other institutional actions, fencing and security have low capital and O&M costs.

3.3.2.1.3 Locked and Labeled Wells—

Effectiveness. Locked and labeled wells would be effective in limiting access to new or existing monitoring wells that penetrate the SRPA under the INTEC. Locked and labeled wells alone would not meet RAOs but could help meet RAO I in combination with other technologies. Locked and labeled wells would be effective in minimizing the potential human health risks posed by contact with the contaminated groundwater beneath the site. However, these access restrictions would not be effective in protecting the environment and are not applicable after the IC period has ended.

Implementability. Locked and labeled wells are easily implemented. Existing monitoring wells within and adjacent to the INTEC are locked at the wellhead and labeled as required by standard monitoring well installation guidance. Services necessary to install locked and labeled wells are common and readily available at the site.

Cost. When compared with other institutional actions, locked and labeled wells have low capital and O&M costs.

3.3.2.1.4 Regulatory (Deed/Zoning) Restrictions—

Effectiveness. Regulatory restrictions would be effective for placing legal or regulatory restrictions on the use of the property and the SRPA resources beneath the site and could thereby meet RAO I. Regulatory restrictions would be effective in protecting human health by restricting agricultural, construction, or other use and development activities that would increase exposure to contaminated groundwater.

Regulatory restrictions by themselves would not be effective in meeting the RAOs or protecting the environment. Regulatory restrictions could prevent drilling of groundwater production wells that could be used for consumption or agriculture. Regulatory restrictions are a reliable method for placing legal restrictions on the use or development of the property and groundwater resources.

Implementability. Regulatory restrictions are administratively feasible and easily implemented. However, restrictions are susceptible to changes in local, state, or federal laws governing the transfer and use of property and to deed adherence and enforcement. Regulatory restrictions do not require any special resources to implement. Legal services would be required to implement regulatory restrictions but are commonly available. Regulatory restrictions have been successfully filed for a parcel of land that was ceded to the Bureau of Land Management from the INL Site and subsequently purchased by Jefferson County.

Cost. When compared with other ICs, regulatory restrictions have low capital and O&M costs.

3.3.2.2 Groundwater Monitoring.

Effectiveness. Groundwater monitoring, as implemented under the Group 5 Monitoring System Installation Plan (MSIP), is assumed to be effective in measuring progress toward RAOs. Monitoring alone would not meet RAOs but could help meet RAOs I and II in combination with other technologies.

Implementability. Groundwater monitoring is currently implemented under the Group 5 MSIP. A large number of monitoring wells currently exist and are monitored at and near the INTEC. Additional wells can be installed as necessary. The resources and services required to implement groundwater monitoring are readily available.

Cost. When compared with other IC actions, groundwater monitoring has moderate capital and O&M costs.

3.3.2.3 Containment. The only groundwater containment process option retained after the preliminary screening is extraction wells. Groundwater would be pumped from extraction wells, creating a cone of depression in the water table.

3.3.2.3.1 Extraction Wells—

Effectiveness. Groundwater extraction wells could effectively contain the extent of the Sr-90 contaminant plume; however, modeling results reported in the OU 3-14 RI/BRA report indicate the Sr-90 plume will not extend beyond the INTEC footprint after 2095.

Implementability. Extraction wells are easily implemented; however, treatment and disposal will be required for extracted groundwater.

Cost. Installing and operating extraction wells for containment would have relatively moderate capital and O&M costs.

3.3.2.4 Removal. The only groundwater removal technology identified is the option of extraction wells. Extraction wells extract the groundwater, creating a cone of depression in the water table. When extraction wells are installed at locations that allow overlapping cones of depression, they effectively remove contaminated groundwater and prevent the contaminants from migrating further downgradient.

3.3.2.4.1 Extraction Wells—

Effectiveness. Based on preliminary modeling results discussed previously, extraction wells could effectively remove sufficient contaminated groundwater from the SRPA to clean up the contaminant plume and meet RAO I.

Implementability. Extraction wells are easily implemented; however, treatment and disposal will be required for extracted groundwater.

Cost. The costs associated with the installation and operation of extraction wells for cleaning up the Sr-90 plume would have high capital and O&M costs, due to the relatively large number of wells and long duration of operations.

3.3.2.5 Ex Situ Treatment. The ex situ treatment GRA includes physicochemical, evaporative, and biological remediation technologies. The physicochemical treatment technologies retained after the preliminary screening include ion exchange and RO. Evaporative treatment technologies retained after the preliminary screening include using a new evaporator or evaporation ponds. Retained technologies are evaluated below.

3.3.2.5.1 Ion Exchange—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. The effectiveness of ion exchange depends somewhat on the concentration of naturally occurring competing ions (calcium for Sr-90) and on the resins. The available data indicate that several commercially available, specific resins can remove Sr-90 in cationic form (i.e., Sr^{+2}). Testing at the INL Site on some groundwater wells (Garn et al. 1997) has shown Sr can be removed.

Implementability. Ion exchange is easily implemented, but it requires additional treatment process options, i.e., resin drying for disposal of spent resin and discharge of the treated groundwater to a percolation pond. It may be a requirement or a desire to regenerate resins. The regenerant would be evaporated to reduce volume and water content prior to disposal.

Cost. The costs associated with ion exchange are expected to be low to medium compared to other ex situ treatment technologies, depending on the design scenario selected. This assessment is based on the capital costs to dispose of the depleted resins if not regenerated and the potential volume of groundwater that will be extracted and require treatment through the life of the remedial action. Without resin regeneration, this option would likely have a high cost.

3.3.2.5.2 Reverse Osmosis—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. The effectiveness of RO depends on the membrane type, operating pressure, and the concentration of the COCs. Pretreatment of the groundwater would be necessary to remove minerals and oxidants (nitrates) that attack and foul the membranes.

Implementability. RO is easily implemented but requires additional treatment process options before and after ion exchange.

Cost. The costs associated with RO could be relatively high compared to other ex situ treatment technologies. This assessment is based on the capital costs to pretreat the groundwater and the disposal of the depleted resins and on the potential volume of groundwater that will be extracted and require treatment through the life of the remedial action.

3.3.2.5.3 Filtration—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. Filtration may be used as a groundwater pretreatment prior to other unit processes. Filtration alone would not remove dissolved Sr-90.

Implementability. Filtration is easily implemented compared to other ex situ treatment technologies.

Cost. Capital costs for filtration are relatively low compared to other ex situ treatment technologies. O&M costs are moderate because periodic filter media replacement and disposal are required.

3.3.2.5.4 Evaporation Ponds—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. Evaporation ponds would be effective during summer months, but the effectiveness could be greatly reduced during winter months. Additionally, placing radiologically contaminated water in evaporation ponds may result in potential releases to the air. The rate of evaporation may not be sufficient to handle the volume of water pumped from the SRPA by an extraction system if used as a primary technology. However, if used as an adjunct, i.e., side streams from other processes, it is expected to be effective.

Implementability. Evaporation ponds can be easily implemented. An evaporation pond system to address the estimated 300 to 3,000 gpm of water potentially extracted from the SRPA would require a very large area, on the order of hundreds of acres and would likely not be technically feasible. However, for treatment of smaller secondary waste streams, e.g., ion exchange column regenerant, evaporation ponds could be of a feasible size.

Cost. The costs associated with evaporation ponds could be relatively high compared to other ex situ treatment technologies if used as a primary technology. This assessment is based on the capital costs that would be necessary to site, construct, and ultimately close the evaporation ponds. The rate of evaporation is highly variable as it is dependent on the weather. The design would need to be sufficient to handle the volume of groundwater (if primary technology) extracted during winter, including precipitation and off-normal storm events. Disposal of the sludge containing the contaminants is an additional cost, dependent on the volume of groundwater extracted and the life of the remedial action. For a small pond handling a side stream, such as ion exchange regenerant, costs are expected to be low.

3.3.2.5.5 New Evaporator/Distillation Column—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. Evaporation eventually results in a clean liquid stream and solids concentrate (i.e., reduction in waste volume). The contaminated groundwater could be transported to a new evaporator at the INTEC for concentration or used as an ancillary to other processes. The bottoms product would need to be treated further, e.g., dewatering/solidification, as well as the distillate that would also need treatment, ion exchange, for example.

Implementability. This is more difficult to implement if the entire groundwater flow is treated. However, as an adjunct process, it is easy to implement.

Cost. The costs associated with using a new evaporator could be relatively high compared to other ex situ treatment technologies. This assessment is based on the volume of groundwater that could be pumped through the life of the remedial action and the disposal of the sludge containing the contaminants, if used as a primary process. However, as an adjunct process, the cost of this is expected to be low to medium.

3.3.2.6 Disposal. Disposal options involve the INTEC percolation ponds, injection wells, and evaporation ponds.

3.3.2.6.1 INTEC Percolation Ponds—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. The new INTEC percolation ponds could be used to effectively dispose of flows less than about 690 gpm that meet the WAC.

Implementability. Disposal to the new INTEC percolation ponds could be implemented relatively easily by connecting the treatment process effluent lines to the service waste conveyance system. However, the availability of the ponds during the pumping period is unknown because there is no planned closure date for the ponds.

Cost. Costs for disposal to the percolation ponds would be relatively low because all required infrastructure is in place.

3.3.2.6.2 Injection Wells—

Effectiveness. Groundwater treatment, in combination with groundwater extraction from pumping wells and disposal, may potentially meet RAOs I and II. The use of injection wells is an effective means of disposing of treated groundwater into the SRPA.

Implementability. Disposal using injection wells is easily implemented, but the size and number of injection wells needed to handle the volume of extracted and then treated groundwater will need to be determined.

Cost. Injection well costs are relatively low compared to other disposal options.

3.3.2.6.3 Evaporation Ponds—Evaporation ponds are evaluated in Section 3.3.2.5.4 as a treatment option. That evaluation applies to their use for disposal of treated water as well.

3.4 Representative Process Options

RPOs selected based on the evaluation of process options for tank farm soil and the SRPA are listed in Table 3-3 and Table 3-4, respectively. The RPOs selected were determined to be the most potentially effective and implementable, and lowest cost, of the process options considered for each technology type. The RPOs selected were used to develop the alternatives presented in Section 4.

RPOs were not selected for every technology type, e.g., in situ biological treatment of soil, based on lack of demonstrated effectiveness or implementability. These technologies were not screened out but are available to be advanced to treatability studies if the identified RPOs are considered inadequate.

The RPOs carried forward to alternative development are intended to represent the group of process options identified in the screening process and are considered the most effective and implementable of the options surviving screening. The initial selection of RPOs may be revised in the ROD based on public comment on the Proposed Plan or other considerations.

The RPOs were selected using engineering judgment. In some cases, more than one process option was selected for a technology type, for example, if two or more process options were considered to be sufficiently different in their performance that one would not adequately represent the other or if the processes are complementary or part of a treatment train. Innovative technologies were selected as RPOs only if they were judged to provide better treatment, fewer or lower adverse effects, implementable within a reasonable time period, or lower costs than other established process options. The specific process option actually used to implement the remedial action at a site may not be selected until the remedial design phase.

Table 3-3. Summary of representative process options for use as components of remedial alternatives for tank farm soil.

General Response Action	Technology Type	Representative Process Option	Basis for Selection
Institutional controls	Access restrictions	Visible restrictions	Effective, currently implemented, low cost.
		Access controls	Effective, currently implemented, low cost.
	Property transfer controls	Deed or regulatory restrictions	Effective, currently implemented, low cost.
	Administrative controls	CFLUP	Effective, currently implemented, low cost.
		Public notices	Effective, currently implemented, low cost.
		DOE directives	Effective, currently implemented, low cost.
		NEPA (DOE environmental checklists)	Effective, currently implemented, low cost.
		Work controls	Effective, currently implemented, low cost.
		Notice of soil disturbance	Effective, currently implemented, low cost.

Table 3-3. (continued.)

General Response Action	Technology Type	Representative Process Option	Basis for Selection
Surveillance and monitoring	Monitoring	Surface soil sampling and radiochemical analysis	Effective for determining extent of Cs-137 and Sr-90 contamination; available both on-Site and commercially; moderate to high cost.
		Gamma monitoring	Effective for determining extent of Cs-137 contamination; available both on-Site and commercially; low cost.
Containment	Capping	ET cover	Demonstrated effectiveness on INL Site; design and construction commercially available; low cost.
		Conventional asphalt	Part of TFIA remedy in place, commercially available, effective for reducing infiltration, controlling surface water drainage, low cost.
		MatCon asphalt	Commercially available, effective for reducing infiltration, controlling surface water drainage, moderate to high cost.
	Surface water management	Maintain/expand TFIA	Effective for reducing infiltration, controlling surface water drainage. Remedy already in place, low maintenance costs.
In situ treatment	Physicochemical	Grout injection	Demonstrated effectiveness for immobilizing Sr-90; not effective for reducing Cs-137 direct exposures; design and implementation commercially available; moderate-high cost.
Removal	Excavation	Conventional excavators	Demonstrated effectiveness; design and implementation commercially available; low cost.
		Remotely controlled excavators	Demonstrated effectiveness; design and implementation commercially available; high cost.
		Vacuum excavators	Demonstrated effectiveness; in use at tank farm; moderate cost.
Disposal	Landfilling	ICDF	Available within INTEC AOC; lowest-cost soil disposal option.

Table 3-4. Summary of representative process options for use as components of remedial alternatives for SRPA groundwater.

General Response Action	Technology Type	Representative Process Option	Basis for Selection
Institutional controls	Access restrictions	Visible restrictions	Effective, currently implemented, low cost.
		Access controls	Effective, currently implemented, low cost.
	Property transfer controls	Deed or regulatory restrictions	Effective, currently implemented, low cost.
	Administrative controls	CFLUP	Effective, currently implemented, low cost.
		Public notices	Effective, currently implemented, low cost.
		DOE directives	Effective, currently implemented, low cost.
		NEPA (DOE environmental checklists)	Effective, currently implemented, low cost.
		Work controls	Effective, currently implemented, low cost.
		Notice of soil disturbance	Effective, currently implemented, low cost.
Surveillance and monitoring	OU 3-13 Group 5 MSIP monitoring	Sampling and analysis for COCs, water levels	Effective, already implemented, moderate cost.
Containment	Groundwater pumping	Extraction wells	Potentially effective, implementable, moderate cost.
Removal	Groundwater pumping	Extraction wells	Effective, implementability uncertain, high cost.
Ex situ treatment	Physical	Filtration	Effective as a pretreatment, implementable, relatively low cost.
	Physicochemical	Ion exchange	Effectiveness would be established by a treatability study; implementable, relatively low to moderate cost.
Disposal	Disposal	INTEC existing percolation ponds	Effective, implementable, low cost.
		Reinjection wells	Effective, implementable, moderate cost.
		New evaporation ponds	Effective, implementable, high cost.

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